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ABSTRACT

Actions taken immediately after a terrorism act involving radioactive materials are critical for human health and safety and environmental protection. The appropriate actions are based on an assessment of the impact the release of radioactive material had or could have on the affected region. Typical risk assessment methods are either ecological or human health based. There have been calls to integrate the two approaches but, as of yet, no integrated methodology has been developed. A terrorist act which could negatively impact both the ecology and human health is an ideal motivation for integration of the two approaches since the assessment must be done quickly and funds are likely to be limited. The proposed assessment approach, termed the Level of Impact Analysis, introduces an integrated assessment model involving a pre- and post-Radiological Dispersal Event (RDE) assessment of a region. Subsequent steps allow for integration of real-time data and results in a flexible and adaptive approach to recovering from a RDE. The result is a methodology that allows for a quick assessment of risk, comparison of options, and prioritization of recovery actions. There is a question regarding the legal mandate for cleaning up a site contaminated from a terrorist event. The Comprehensive Environmental Response, Compensation and Liability Act of 1980 is the expected default statute. Changes to the scope of this law to better address terrorist acts are suggested. Policy considerations such as educational reform, funding and risk communication are discussed within the context of recovery from a RDE.

DEDICATION

Dedicated to my best friend -- my wife, [redacted] Thank you for twenty-one years of unwavering love, support and encouragement.

To my two beautiful daughters, [redacted] thank you for your support and love. You can accomplish anything worthwhile with diligence, hard-work and patience.

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CHAPTER 1

INTRODUCTION

1.1 Overview

The terrorist attacks on the United States on September 11, 2001, resulted in the loss of nearly 3,000 individuals and changed our myopic view of the world and how others perceive us as a nation. Furthermore, it was the driving force in the creation of a new department within the U.S. government and expenditures of hundreds of millions of dollars on efforts to prevent future attacks.

Terrorism is defined in many ways, but at the heart of any definition is the intent of the perpetrators to instill fear and panic and create disruption. Terrorists seek targets providing a platform for delivery of their message. They make attack decisions based on which target will provide the most "bang for their buck", considering availability of resources, accessibility to the target and impact. Financial institutions, national monuments and military targets probably have been or are being considered as potential targets. Nevertheless, environmental terrorism could have a broader impact, causing economic disruption in towns, counties or even large cities. A critical node within the environment is our drinking water supply. President George W. Bush recognized the importance of

this asset, and on 12 June 2002 signed into law the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (Public Law 107-188). Within this law is an amendment to the Safe Drinking Water Act (SDWA) requiring communities of more than 3,300 individuals to assess their water source for potential terrorist attack. The intent of this act is to assess vulnerability in hopes of *preventing* an attack. There are very few certainties in this world; absolute prevention is not one of them. So, the question is what should be done if and when an attack occurs -- particularly if the attack is on an ambient water source that serves or affects potentially millions of people? Ambient source waters (surface or ground) can serve many people, are difficult to protect in their entirety and costly to remediate if large areas are affected.

A terrorist attack affecting source waters may not only adversely affect the drinking water quality and available quantity; it might also have a dramatic impact on the ecology and economy within and outside the region served. Having decided on a target, what would be a tactically efficient choice of contaminating agent? Chemical and biological agents are certainly possible choices, but these sometimes require advanced laboratory preparation and/or access to source materials. Radioactive materials, on the other hand, are widely used and require little preparation prior to dispersal. A likely choice would then be a radiological dispersal device or RDD (also referred to as a "dirty bomb" when explosives are involved). In the context of this study, deployment of a RDD will be referred to as a radiological dispersal event (RDE) and will not include the use of explosives.

Due to the lack of a definition in the literature for a RDE the following is provided:

Radiological Dispersal Event (RDE): An intentional act of distributing or placing radioactive materials in any form in such a way so as to inflict harm, create a disturbance, cause damage (physical, biological or psychological) or instill fear among people not directly involved in military or governmental actions for or against foreign entities. Specifically excluded from this definition is any event utilizing or threatening the use of weapons capable of a nuclear yield.

Some reports indicate that use of a RDD is not an "if" scenario but a "when" (Allison, 2004). While a RDD will not cause the devastation of a nuclear weapon in terms of lost lives and infrastructure, it is likely to cause widespread panic, economic disruption and a sense of fear among the public due to the perceptions and images of ghastly consequences associated with radiation. This latter point makes it an ideal selection as a terrorist tool (Johnson, 2004).

It is widely accepted that "radiation" instills a sense of fear in the minds of the public. The nuclear age started under a cloak of secrecy. The U.S. government has admitted within the last two decades to human testing involving administration of and/or exposure to radioactive materials, following years of denial of existence of such a program. Images of vast destruction from Hiroshima and Nagasaki -- entire cities laid to waste in the blink of an eye -- are still widely published. Add to these the ubiquitous reports of global terrorism, reports of lost

radioactive material and the supposed ease with which one can obtain such material and you have a formula for an effective terrorism tool.

1.2 Problem Statement

The literature provides a wealth of information regarding what to do in the immediate aftermath of an attack involving various disasters including weapons used by terrorists (Wein *et al.*, 2003; NCRP, 2001; DHS, 2003). These consist of the critical steps required to secure the area, care for the wounded, prevent as many additional casualties as possible and protect the crime scene. First responders are trained to treat the patient immediately if life or limb is in danger prior to consideration of the radioactive contamination (NCRP, 2001). Civil authorities secure the area from unauthorized access, and the crime scene investigators enter the area to collect and analyze evidence.

There is, however, no standard guidance on what to do next, i.e., after any casualties are treated and the crime scene investigation is completed. Steps must be taken to prevent the spread of contamination, protect public health, minimize environmental, economic and psychological damage, remediate the site, and keep the public informed. Time is of the essence. Quick action is crucial to preventing the spread of contamination, minimizing damage to the ecology and local economy and calming the public. Policy recommendations are needed to guide local, state and, possibly, federal officials as they plan for and work together to deal with the aftermath of an RDE. Without such guidance, each government agency might operate independently, evaluating all options within the confines of

their scope of responsibility and developing a plan before beginning to take the important action outlined above. Most government agencies do not have the human or financial resources required to independently prepare and implement an effective, multidisciplinary plan which would be required for a RDE. Furthermore, once a RDE has occurred, there is not time to develop and implement a recovery and assessment plan in the typical fashion. A developed recovery plan, prior to the event, could include a provision for information release about radiation and the potential impact regarding a RDE. The regular dissemination of this information could serve to educate and prepare the public to respond properly in the event a RDE occurs.

Large numbers of critical injuries are not likely to ensue following deployment of a RDD or RDE (Ring, 2004). There will be no nuclear detonation. Panic, fear and mistrust will be at the forefront of the minds of the potentially affected individuals (Johnson, 2004). How do we proceed with the consequence-management phase once left with the remains of this insidious act? We must press forward to protect the health of residents and to protect, preserve and remediate the ecology, i.e. the *environment*. To date there are no consensus standards or guidance regarding environmental cleanup following deployment of a RDD (Elcock, Klemic, & Taboas, 2004). A risk assessment will provide critical and timely information necessary for officials to make informed decisions regarding the appropriate actions to take. Furthermore, there is yet to be defined a clear and concise assessment methodology to follow after the use of a RDE and a corresponding policy for decision-makers to follow. Application of traditional

risk assessment methods is not applicable to emergency events (Suter, Efroymson, Sample, & Jones, 2000) such as a RDE.

Following a terrorist event involving radioactive materials there is likely to be confusion on the part of decision-makers. The confusion will be due, in part, to failure to have developed and implemented a concise, practical assessment methodology that can be completed within limited monetary and temporal constraints. In order to preserve limited resources and streamline a potentially monumental undertaking such as remediation of a radiologically contaminated site, we must have, in place, a methodology to effectively assess the impact in a reasonable amount of time to ensure required services are retained and longer-term consequences are managed (Karam, 2005). In addition to the risk posed by the contaminating agent, there are additional considerations vital to the efficient and practical outcome: economic impact, societal value of resources and cost of remediation, to name a few.

The Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (P.L. 107-188) requires public utilities to evaluate their vulnerability to a terrorist attack but does not address the response after the fact. Furthermore, some cities could lack the appropriate resources (financial, scientific or planning and development) to adequately consider the unique aspects of a RDE. Response capabilities are generally limited and designed for traditional releases, e.g. transportation accidents and industrial releases. As a practical example, the City of Dayton, OH falls into this category. They have well-developed plans for emergency responses managed by the Environmental Management Team within

the Division of Water. What they do not have, is a program which defines how an impact from a radiological release will be assessed.

The risk assessment community has recently begun looking at risk assessment in a more holistic manner by attempting to integrate the human health and ecological aspects into one assessment (Cirone *et al.*, 2000). Within the risk assessment community, it is common to consider human health risk separately and distinctly from ecological risk. It has been proposed that these two approaches be combined in an integrated fashion to provide a more complete product (Munns *et al.*, 2003, Cirone *et al.*, 2000). The study discussed herein utilizes an integrated ecological and human health assessment within the context of a RDE. The U.S. Environmental Protection Agency (USEPA) has conducted ecological and human health risk assessments separately for approximately twenty years. Environmental law has developed over the last thirty-plus years with these two considered fundamentally different and separate. The legal framework stipulates protection for "human health and welfare" and the "environment". Within the context of this study, the "environment" is all things – biotic and abiotic, human and ecological.

As will be shown in the next chapter, recent risk assessment experts are calling for the integration of these approaches for traditional risk assessments. As a result of our changing world and in preparation for potential terrorist attacks, the time for integration is now. Integration provides a holistic, efficient approach and recognizes the interconnectedness of "human health and welfare" and the "environment".

1.3 Study Intent

The purposes of the study are to:

1. Develop a holistic approach to assess the impact of a RDE based, primarily, on the integration of the human health and ecological risk assessment methodologies used by the U.S. Environmental Protection Agency (USEPA) as published in the *Risk Assessment Guide for Superfund* (human health and ecological).
2. Consider and propose data requirements for an integrated impact assessment.
3. Generally outline the crisis-management phase as it currently exists including the definition of the roles and responsibilities of agencies in the recovery or consequence-management phase.
4. Analyze the Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended, (P.L. 96-510) for application in the response to a RDE.
5. Propose general policy recommendations for preparing for and recovering from a RDE.
6. Outline recommendations for future research, using Dayton, OH as an illustrative example due to the collocation of the sole source aquifer recharge area and major industrial, educational and military facilities. This area is of critical importance and interest due to its unique buried valley aquifer system and the well-developed organizational and institutional framework.

Discussion throughout this study will be focused on the recovery phase, but due to the required continuity between the pre-RDE and post-RDE response and recovery phases with regard to risk communication, for example, there will be a need for some elaboration on the response aspects. This will be provided solely for the purpose of orientation within the context of the study.

The goal and major contribution of this study is to produce a usable assessment approach based on the integration of current ecological and human health risk assessments framed within the time and resource restrictions of an emergent situation. The conceptual model provided in Chapter 4 illuminates the ideas and concepts while the Level of Impact (LOI) equation provides a simple, yet meaningful, method of quantitatively assessing the impact.

The approach involves a pre- and post-RDE phase assessment of an area or region. (The selection of the region of interest is based on a threat analysis and prioritization, not discussed in detail in this study.) During the pre-RDE phase, accumulation of the required physical data on the region, identification of stakeholders and resolution of the desired end-state, i.e. cleanup goals and methods, are accomplished. This is possible due to the well-known and scientifically proven effects and limited radioactive material varieties available for terrorist use. Once the RDE has occurred the crisis-management phase will result in the accumulation of real-time data. During the problem reformulation step, the current information is fed into the iterative LOI analysis loop and allows for adjustments to the pre-assessment analysis. This provides an adaptive and flexible approach requisite for efficient recovery from a RDE. Based on an

integrated ecological and human health risk assessment methodology a quantitative risk value is determined. This value, as well as several other parameters unique and pertinent to the affected region, is used in the LOI equation to provide a value which allows for a quick assessment, comparison of options, and prioritization of recovery actions.

1.4 Assumptions and Limitations

A primary assumption in this study is that a RDE has occurred, the investigative phase has been completed, and the crisis-management phase has transitioned into the consequence-management phase. Thus, in accordance with the National Response Plan (DHS, 2004), remedial actions have been transferred from the Department of Energy (DOE) to the USEPA. However, some aspects, such as risk communication, are integrated across all phases and will be addressed for the entire spectrum of recovery.

The intended application of this study is on the release within an unconfined water source such as the ambient water source feeding or recharging an aquifer, i.e., surface and ground water. A more detailed analysis of a scenario such as this is proposed for future work in Chapter 6. References will be made to resources, e.g. natural, political and organizational, within the Dayton, OH area as this area is an ideal model for future research. However, this approach has potential application in other recovery activities and other terrorism acts. An effective release, from a terrorist's perspective, would be targeted to densely populated areas, areas of significant historical, economical or military value, or critical

infrastructure. The process presented, then, is an approach that can be used for various areas based on known or anticipated information and/or data and can be modified for these scenarios. For example, a contaminated, rural region containing a historically significant area could place a higher value on that area than an urban region downstream from the release and, therefore, choose to modify the approach to ensure the historical area is left intact.

Proposed within this study is a theoretical integrated assessment approach that cannot, at present, be independently validated because it could require local and state adoption and the acceptance and participation of a significant number of stakeholders as discussed later. The endeavor to organize all stakeholders is not inconsequential and its consideration herein would exceed the scope of this study. Identifying, contacting, and meeting with stakeholders is an important aspect of the successful implementation of the integrated approach and should be adopted and implemented as early as possible in the planning stage.

Because the concept of a RDE is relatively novel and as of yet untried, literature regarding this specific scenario is lacking. Therefore, an extrapolation from existing literature on nuclear waste siting, reactor siting, nuclear technologies and terrorism, in general, is used as the basis for the discussions presented. Likewise, risk assessment methodologies are not clearly defined for such a scenario, thus resulting in the theoretical approach presented herein. Further, a data set for this specific scenario from which information can be culled to verify the method does not exist. Lastly, there is no defined method for "field testing" or "exercising" the proposed theory. Table top discussions or exercises

are useful methods for evaluating and understanding *response* capabilities but this is beyond the scope of this study. Therefore, the further research proposed in Chapter 6 is presented as a way of better understanding and defining the issues associated with a RDE within a specific area.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This study is a multidisciplinary approach to addressing the aftermath of a unique problem facing the world today. Terrorism, although not new, has recently become a multi-national issue due its ever-increasing use throughout the world and innovative methodologies. Use of a radiological weapon can be focused on dense population areas or rural, agricultural areas (Van Moore, 2004). Its potential use has gained significance in the United States following the attack on 11 September, 2001. As a direct result of this event, President George W. Bush initiated the creation of a completely new, cabinet-level department. The Department of Homeland Security (DHS) was created under the Homeland Security Act of 2002 (H.R. 5005) with the mission of preventing or deterring terrorist attacks. Moreover, DHS is the lead agency with regard to response and recovery following a terrorist attack.

The use and dispersal of radioactive materials has been cited as an event that is overdue (Allison, 2004) and growing in likelihood (Tucci & Camporesi, 2003). The threat from nuclear/radiological, biological and chemical attacks by terrorists is a great concern (Bugliarello, 2005), and preparations must be made

before such an attack if we are to be able to respond appropriately and efficiently. "The threat of radiation terrorism is no longer remote and can happen suddenly anywhere" (Tucci & Camporesi, 2003). Bugliarello (2005) further notes that there is not an overall, coordinated plan for a response to a terrorist event in an urban area.

The idea of utilizing radioactive materials as a tool in war is not new. General MacArthur suggested using radioactive materials to deny Chinese access at the Korean and Chinese border during the Korean War (Manchester, 1978). The actions to follow in the aftermath of such an event have also been identified as an area requiring further research and one that is lacking a clear, concise, effective and efficient plan. Elcock *et al.* (2004) noted that in the event of a radiological dispersal event there is likely to be confusion as to how to proceed with the cleanup of the affected areas. Debate over which agency and/or which risk assessment methodology to use is ongoing. Current risk assessment methodologies are not adequate for such a scenario. Future decisions and policies made on the basis of traditional risk assessments require a method fundamentally different from those currently conducted (Putzrath & Wilson, 1999). Risk assessment is a tool enabling officials and stakeholders to make decisions or to choose actions based on incomplete information (Schulte, 2003).

The majority of the scientific literature cited below refers to the use of a radiological dispersal device (RDD) using an explosive as a method for dispersing radioactive material. Based on this literature, methods, procedures, outcomes and assessment methods are extrapolated and applied to a RDE, as defined in Section

1.1. Furthermore, because the literature is lacking substantially in the area of an intentional release of radioactive material within a water medium, further extrapolation from radioactive waste site assessments, terrorism in general and risk perception regarding nuclear technology is used herein for comparison to a RDE.

This literature review is divided into subsections according to pertinent areas of the study. Information regarding water and its vulnerability is presented to provide the reader with a brief overview of its importance. A section then follows on the details of a RDE: its definition, potential radioactive materials that can be used in a RDE and general information regarding the availability of the material, cost of remediating areas contaminated with radioactive material, possible societal and regional economic impact and complications associated with its use.

The legal issues regarding the cleanup or remediation of a site affected by a RDE are significant. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, (CERCLA) appears to have at least some applicability to a RDE. Presented in Section 2.4 are the areas of the Act that could lead to its legal application and those that might prevent its application.

Section 2.5 includes information regarding the implications and applications of public policies to a RDE. One potentially difficult aspect of an RDE is its "wicked" nature (Rittel & Webber, 1973). This section identifies the concept of a wicked, or intractable, problem and some considerations regarding adoption of sound public policy with respect to a RDE. A major consideration of sound

policy is stakeholder participation. The concept of stakeholder participation is discussed and potential stakeholders are identified. The method or principle forming the framework of the policy is clearly an issue. Two principles are presented: precautionary and adaptive. The precautionary principle has historically been associated with environmental issues. The adaptive management strategy has been identified as a method of dealing with intractable issues.

There are two overriding risk assessment approaches. Ecological risk assessment methods involve a comprehensive look at an ecosystem. Human health risk assessment focuses on the adverse impact on humankind in the event of a release of a contaminant. Information presented in Section 2.6. is relevant to the application of these methods to a RDE. The integration of these two methods has been noted as a novel approach to conducting risk assessments, and literature pertinent to this endeavor is presented.

A risk assessment can not be conducted in a vacuum. The stakeholders' perception of risk must be addressed in the assessment and communication of the risk. Risk perception literature specific to nuclear technology, radiation and terrorism is presented in Section 2.7. The communication of the risk, with respect to radiation and terrorism, is daunting. It has been largely unsuccessful in the past. Historical pitfalls of risk communication are presented as are suggestions for dealing with radiological terrorism. Section 2.9 is a conclusion of the literature review and a summary of the material presented in Chapter 2.

2.2. Water and its Vulnerability

Water is a vital, limited resource. Vulnerability assessments are now required for public distribution systems. However, vulnerability assessments of ambient water sources (surface and ground water) are not only not required but rarely considered. Chapter 6 includes a unique and significant consideration for further research and application of the proposed framework presented in this study. The following general information is presented in anticipation of an ongoing study subsequent to this one, but this information is limited because the scope of the current study does not involve the identified area. Therefore, additional reference information is provided in Chapter 6. The Great and Little Miami River Buried Valley Aquifer System, located in the Mad River Well Field near Dayton, OH, is the source of drinking water for approximately 90% of the residents in that area according to Mr. Rich Bendula, Manager, Division of Drinking and Ground Waters, Ohio Environmental Protection Agency (personal communication, May 13, 2005). Within the Mad River Watershed, ground and surface water serve to recharge the three aquifer systems located within the Mad River Watershed (MCD, 2004). The Great and Little Miami Buried Valley Aquifer System was designated a Sole Source Aquifer (SSA) in 1988 by the USEPA (MVRPC, 2005). The Mad River watershed is a sub-component of the Upper Great Miami River system. An aquifer is defined as a sole source aquifer if the aquifer supplies at least 50% of the drinking water to the overlying area and there is no physically, legally or economically viable alternative for the region (USEPA, 1987).

Water has been identified as a resource of fundamental concern when assessing the risks of damage to it (McDaniels, Axelrod, Cavanaugh, & Slovic, 1997). Much has been disclosed about the vulnerability of public water systems and their supporting infrastructure. In fact, a special joint conference held by the Universities Council on Water Resources (UCOWR), National Institutes for Water Resources (NIWR) and the Environmental and Water Resources Institute of the American Society of Civil Engineers (EWRI), held from 30 July through 1 August 2003, was devoted entirely to water security. The Journal of Contemporary Water Research and Education dedicated an entire issue to water and homeland security with titles such as "Assessing the Vulnerabilities of U.S. Drinking Water Systems", "Water Treatment and Equipment Decontamination Techniques" and "Safeguarding the Security of Public Water Supplies Using Early Warning Systems: A Brief Review" (Universities Council on Water Resources, 2004).

The vast majority of literature regarding water security is dedicated to the protection of the infrastructure at the water utilities' node. Presidential Decision Directive 63 (PDD 63), signed by President Bill Clinton, was superseded by Homeland Security Presidential Directive 7 (HSPD 7), signed by President George W. Bush. Both Directives direct federal agencies to identify and prioritize critical infrastructure and key resources within the U.S. in need of protection from terrorists (Danneels & Finley, 2004). Within these directives is the appointment of the USEPA as the lead agency for water infrastructure, which includes both drinking and wastewater systems. The Bioterrorism Security Act of 2002 requires

community water systems serving more than 3,300 individuals to review and identify their vulnerabilities (PL 107-188). This law generally is directed at an analysis of infrastructure including pipes, physical barriers to the system and systems or methods of water treatment. It does not, however, address evaluating the vulnerability of the water in its ambient state prior to entry into the community water system.

Danneels and Finley (2004) note that the water supply system is probably taken for granted within the context of the 14 U.S. infrastructures noted in HSPD 7, and it will take a large investment to provide even "minimal levels of security". In his development of a model for involvement in vulnerability assessment of systems, Hellström (2005) states the reduction of vulnerability must include participation from employees before, during and after an event, and the level of involvement is dependent on social factors.

Remediating contamination is a costly, time-consuming venture (Kaplan & McTernan, 1993). One of the critical issues is "how clean is clean?" (Kaplan & McTernan, 1993). This point has been identified by Elcock *et al.* (2004) as a critical question that must be answered in policy (although it will not be answered, quantitatively, herein). Ground water remediation is technologically limited and expensive. When coupled with the perception of risk from radiation, these factors can lead to conflict when selecting an appropriate remediation method (Kaplan & McTernan, 1993). It was noted in a recent USEPA report (USEPA, 2004) that the USEPA has initiated an intense effort to improve analytical monitoring and to detect biological, chemical and radiological

contaminants in drinking water systems in hopes of preventing significant economic disruption.

2.3. Radiological Dispersal Device and Event

2.3.1. Definition

There are several terms, such as nuclear terrorism, "dirty bomb", and radiological terrorism, commonly associated with the term radiological dispersal device (RDD), and they are often used interchangeably throughout the literature. A review of the literature indicates most authors use similar definitions for a RDD, the majority of which are focused on the dispersion of radioactive materials via an explosive device. What is clearly absent in the literature is the definition for a radiological dispersal event (RDE), although the term is referenced occasionally (Elcock *et al.*, 2004; NCRP, 2001). Allison (2004) associates the term RDD with a "dirty bomb" and defines it as the use of conventional explosives to spread radioactive material. Ferguson, Kazi, and Perera (2003) and a report published by the U.S. Central Intelligence Agency (2003) titled *Terrorist CBRN: Materials and Effects (U)* classify RDDs in one of two ways. An "active" method utilizes an explosive device, as defined above, and a "passive" approach employs non-explosive methods such as spreading radioactive materials by aerosolizing the material or placing it in a public area, thereby causing the intentional exposure of individuals to the radioactive material. Ferguson *et al.* (2003), specifically mentions dissolving radioactive materials in a water reservoir as a form of a RDD. Ring (2004) and the NCRP (2001) further support the

common definition of a RDD as one intended to disperse radioactive material utilizing a conventional explosive.

Snowden (2003) provides a general definition of a RDD as a "... device other than a nuclear explosive (bomb) that is specifically designed to disseminate radioactive material to cause destruction, damage, or injury." Furthermore, the dispersion is intended to scatter radioactive matter over a wide area.

2.3.2. Why a RDE might be used

There are at least three major reasons why a terrorist might consider using radioactive materials. First, radioactive materials are accessible (Conklin & Liotta, 2005). Second, environmental cleanup is expensive and time consuming (Gray, 1995). Third, the psychological or complicating effects due to the polarity on positions regarding radiation and/or nuclear technology are significant (Mihai, Milu, Voicu, & Enachescu, 2005).

2.3.2.1. Availability

As terrorists have attempted to deploy radioactive materials (Steinhausler, 2005) within the U.S., the presented scenario is plausible. There are researchers who dismiss radiological terrorism as a plausible event, but Maerli *et al.* (2003) claim doing so might be dangerous and that radioactive materials should not be overlooked or under considered.

Orphaned materials and/or sources are those that have been discarded or abandoned without proper identification, notification or disposal. There are over

2,000,000 radiation sources in use within the U.S. (Conklin & Liotta, 2005). The U.S. Nuclear Regulatory Commission (USNRC) reports that an average of 375 radioactive sources or devices are lost or stolen each year (Lubenau & Strom, 2002). Without proper disposal and monitoring these sources can be available for use by terrorists.

In a report released in 2001 by the Monterrey Institute for International Studies, it was indicated that some terrorist groups were interested in obtaining materials to use as a radiological weapon (McCloud & Osborne, 2001). "It has become evident that – as one of the possible malevolent acts involving radioactive material – terrorists want to disperse radioactive material." (Steinhausler, 2003).

2.3.2.2. Post-RDE expense

Water infrastructure protection and remediation are costly. Remediating an aquifer is even more so. One aspect of nuclear terrorism has been reported as economic disruption (Geelhood & Wogman, 2005).

Dr. Henry Kelly (2002), President of the Federation of American Scientists, stated in testimony before the Senate Committee on Foreign Relations that radiological attacks present a credible threat and could contaminate large urban areas at levels exceeding currently acceptable USEPA standards. He further stated that residents in rural areas are particularly susceptible to contamination via the water supply. Environmental cleanup expenses ranging in the millions to billions of dollars can be anticipated depending on the parameters of the release, as can be restrictions to access to the affected area based on current USEPA

standards (Kelly, 2002). The result is an impact on the economic and social structure of the affected area; depending on the extent of the event, these effects can spread into areas not directly affected by the RDE.

The cost to cleanup following a RDE is difficult to estimate without specifics regarding the event. In a simulated release of Co-60 in Manhattan (via an explosive device), the estimate to clean the site using current USEPA standards totaled nearly $2 trillion (Kelly, 2002). The type and quantity of radioactive material, release point, area affected, demographics and topography are but a few of the aspects of the release needed to fully evaluate the situation and estimate the costs. However, authors are quick to point out that costs are expected to be significant, and the economic impact might be felt beyond the immediate area of cleanup (Leidholdt, Williams, & McGuire, 2003; Lubenau & Strom, 2002).

Disposal costs alone are significant. The cost estimates for the disposal of commercial, low-level wastes were estimated in 2000 as $375 per cubic foot (Ryan & Newcomb, 2000). Disposal of the volume of waste generated as a result of remediation following a RDE could easily result in expenditures in the millions. Further, utilizing a material with a long half-life could render an area uninhabitable until decontaminated, which could be expensive and require months to years (Maerli, 2003).

2.3.2.3. Difficulties and psychological impact

The NCRP (2001) has identified three conceptual classifications of events involving the dispersal of radioactive material into the environment. The first is a minor spill or release of materials that can be easily confined, controlled and decontaminated. This event is easily handled by local authorities and does not involve a large expenditure of resources. The opposite is a widespread event involving significant quantities of radioactive material and response by local, state and federal entities. A RDE is one of a spectrum of events typically falling between these two extremes. The level of difficulty in dealing with a RDE is dependent on the location of the event, and many other factors. NCRP (2001) identifies the following as complicating factors in the decision-making process, which contribute to the difficulty of dealing with a RDE.

1. Law enforcement requirements,
2. Public health and safety,
3. Casualties and damage to infrastructure,
4. Psychosocial impact, and/or
5. Environmental concerns.

Miscommunication among organizations (public and private), related to any of the five categories above can lead to misallocation of resources and eventual mistrust by the public of those responsible for the safety and health of persons and the environment.

Deployment of a RDE is ideal, from a terrorist's perspective, because it plays on the fears and perceptions of the public (Johnson, 2004; Ring, 2004). Slovic

(1987) elaborated on the concept of the psychometric paradigm whereby events which are uncontrollable, provide an element of dread and are involuntary contribute to the highest perception of risk regardless of the actual, quantifiable risk. The general public is unaware of the real radiobiological effects of ionizing radiation and bases their impressions and fears on dread and the unknown associated with radiation (Slovic, 1987; Johnson, 2004). Klar *et al.* (2002), in a study conducted on terrorism, identify the major characteristics of terrorism as uncontrollability and arbitrariness. These factors feed into the perception of risk noted above whereby individual perception is magnified.

Terrorists seek to use the unknown to their advantage. Because incidents involving the use of radioactive material have an element of "the unknown" it is a factor that influences the choice of radioactive material as a weapon. Nuclear technologies, and by extension many uses of radiation, are perceived as having significantly greater risks than other technologies (Slovic, 2001).

A radiological weapon could be used as a tool to effect change within a government because of its demoralizing effect (Ford, 1998). The NCRP (2001) notes that radiation incidents have a "powerful potential to create fear and dread."

Terrorists often choose a method of delivery of their message to get them media attention which sensationalizes their position (Maerli *et al.*, 2003). Radiation is an excellent delivery method because it appears to get a great deal more media attention than other risk agents (Rossin, 2003).

Maerli (2003) stated, the "… threat of dispersion of many kilograms of plutonium could make a … device a particularly attractive weapon for a terrorist

group, the threat being enhanced by the general population's fear of radioactivity."

2.3.3. Potential materials

There is a paucity of references in the scientific literature regarding the materials likely to be used in a RDE. However, there are a few independent reports indicating what some experts believe are potential types of materials accessible and usable by terrorists.

Ferguson *et al.* (2003) have identified the following materials as possible sources that could be used in a RDE:

1. Cobalt-60 (Co-60),
2. Cesium-137 (Cs-137),
3. Americium-241 (Am-241),
4. Iridium-192 (Ir-192),
5. Strontium-90 (Sr-90), and/or
6. Radium-226 (Ra-226).

The radionuclides above can be obtained from medical, industrial or military facilities (Gonzalez, 2001). Geelhood and Wogman (2005) confirm that both Co-60 and Cs-137 are viable options as radiological terrorist weapons.

Lubenau and Strom (2002) identified a few types of sources commonly orphaned and, therefore, available for use a radiological weapon. One of the most viable of these is Cs-137. This material can be found in medical facilities where

radiation therapy (specifically, brachytherapy) is performed. Its form is readily dispersible in water and, therefore, a feasible option for a RDE in water.

2.3.4. Societal and environmental impact

Bugliarello (2005) noted that of all the possible effects from a radiological terrorism attack, the political and economic consequences could be more considerable. Existing fears of a release of radioactive material make this a valid concern. Societal effects could be geographically widespread and not contained within specific social and academic classes. This was proven to be the case as a result of the 1987 Goiânia, Brazil, Cesium-137 release. Reviews of the effects of the contamination from this incident reveal that people perceived those persons who were located in the immediate area as "tainted." Economically, the area was affected because local farmers were unable to sell their products, local tourism sharply decreased and some airline pilots refused to fly residents from the area (Becker, 2004).

From this event, the following possible consequences were noted by Steinhausler (2005).

1. Some individuals might refuse to return to the contaminated area regardless of the level of contamination,
2. Commercial activities could be hampered whether a risk exists for workers or not, and
3. Real estate values could depreciate.

The NCRP (2001) noted that the dispersal of radioactive material will require some form of decontamination and remediation, and the actions taken early will have an impact on the restoration of the site. The sooner actions are taken the more likely the effects can be mitigated. A quick, effective response and recovery will assure the public, whereas, a protracted, disjointed response will have the opposite effect.

A water contamination event, as considered in this study, could result in the following consequences (Allgeier & Magnuson, 2004).

1. Adverse impact on public health,
2. Disruption of system operations and interrupting the supply of safe water,
3. Reduction in public confidence in the water supply,
4. Long-term denial of water, and/or
5. High cost of remediation and/or replacement.

Public health issues arising from acute and chronic effects of radiation exposure are expected to be minimal following a RDE within a water medium. However, public mental health issues are likely to be real and could result in a large number of "casualties." The resulting societal impact from this perspective could have far-reaching effects well beyond the geographical borders of the affected region. The remaining potential consequences cited above are plausible, with the reduction in public confidence arguably being the most significant. A lack of confidence in the ability of those responsible for public safety to provide said safety could, quite possibly, have a ripple effect throughout the region,

thereby affecting the ability of the economy to recover and administrative organizations to function.

2.4. Legal Issues

Elcock *et al.* (2004) stated there currently are no U.S. laws which deal specifically with the aftermath of a RDE. They note, however, that the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), as amended, could have applicability and might, in fact, be the default regulation in the event of radiological terrorism. Because the NRP designates the USEPA as the lead agent for remediation following a radiological terrorism event (DHS, 2004), it is logical to assume the USEPA might utilize the existing framework for dealing with a RDE. CERCLA, through use of the Superfund, has been used to remediate approximately 66% of the 1,529 sites listed on the National Priorities List (NPL) (USEPA, 2005). It is, therefore, a well known and accepted program for the remediation of contaminated sites.

Generally, there are two extreme cases for the application of CERCLA with respect to a RDE. Either the act applies as is, or it does not. Between the two ends of the spectrum, cases could be made regarding the application of specific sections of the act. In the *Unites States Code*, the Act is promulgated in Title 42, USC, *The Public Health and Welfare*, Chapter 103, Comprehensive Environmental Response, Compensation, and Liability, Subchapter I, Hazardous Substances Releases, Liability, Compensation, Sections 9601 through 9675 (42 USC, Sections 9601-9675). The National Oil and Hazardous Substances

Pollution Contingency Plan (National Contingency Plan or NCP) is the regulation implementing CERCLA (USEPA, 1989). The NCP is the national plan for responding to and remediating hazardous material releases in the environment (USEPA, 1989). CERCLA was created to "provide for liability, compensation, cleanup, and emergency response for hazardous substances released into the environment and the cleanup of inactive hazardous waste disposal sites" (CIS, 1980).

The basic intent of CERCLA is to ensure the response to and remediation of hazardous waste sites with the intent of assigning liability to the responsible party so that cleanup costs can be recovered. A review of the historical information on CERCLA indicates the scope of the law was originally focused on contaminated sites that had been abandoned and left unattended. This could be applied to a terrorist event such as a RDE if one were to use the broad application of CERCLA as discussed below.

2.4.1. Application of CERCLA

Section 9601, Title 42, USC, provides many definitions indicating the contamination resulting from a RDE might be subject to CERCLA regulations and therefore, eligible for designation as a Superfund site. (Referenced citations from CERLCA are provided in the Appendix.) The various terms defined within the Act, such as ``hazardous substance'', ``environment'', "facility", "natural resources", ``release'', ``remove'' or ``removal'' and ``remedy'' or ``remedial action'' all appear to cover the general release of radioactive material regardless of

its original source, e.g. a terrorist. These terms are each broad in their definition and, therefore, have broad applicability. This appears to be by design, so that hazardous material releases from a wide array of scenarios can be remediated. Salzman and Thompson, Jr. (2003) note that the term "facility" has been loosely applied and covers, "… almost everything." With this in mind, it is reasonable to expect USEPA to apply CERCLA to a RDE site.

Section 9604 grants the President broad authority to protect public health and welfare for any releases posing an imminent hazard. This could be perceived as the case for a RDE. This section grants the President the authority to act quickly to effect a timely removal in order to prevent danger to the public or the environment consistent with the National Contingency Plan. Should the President deem that no other person has the authority to respond in a timely manner, he could direct the response. Additionally, should the RDE be in close proximity to a drinking water supply facility, Section 9618 requires the President to consider the impact a high priority. Finally, under the emergency procurement powers provided in CERCLA, the President can promulgate regulations to describe the specifics under which he could take control and require removal or remediation actions. These actions are to be based on the determination that there is an imminent threat to the environment or human health.

2.4.2. Failure of CERCLA to apply

The following citation from Section 9601, Title 42, USC, represents, what appears to be the only legal exception under CERCLA where a RDE might not be covered.

> (22) "… excludes …(C) release of source, byproduct, or special nuclear material from a nuclear incident, as those terms are defined in the Atomic Energy Act of 1954 [42 U.S.C. 2011 et seq.], if such release is subject to requirements with respect to financial protection established by the Nuclear Regulatory Commission under section 170 of such Act [42 U.S.C. 2210], ..."

This exclusion, discussed further in Chapter 5, could represent a bottleneck in the assessment process that must be addressed prior to a RDE and possibly through a change in law. It is clear that the USEPA will have jurisdictional control over the recovery of the site. In U.S. legislation, funding is tied to promulgation of laws, regulations and national and state directives. In the absence of such direction, allocation of resources is a potential hindrance – one which cannot be allowed after a RDE. Perceptions of risk, discussed below, can be associated with the appearance of preparedness and recovery actions. Without clear legal guidance, the recovery might falter and lead to an increased perception of risk.

With regard to assignment of a potentially responsible party, Section 9607 (b)(1), 42 USC, provides a defense for acts of war. This section specifically deals with assigning responsibility for reclaiming costs and not with application of the law regarding cleanup. The assignment of responsibility is not likely to be an

issue because terrorists typically claim responsibility for their acts so they can gain the recognition or use the act as a platform to make their intended statement.

2.5. Policy Regarding RDE

The threat of radiological terrorism has now passed from a topic of fringe theoretical debate to an operational issue for policy makers (Levin & Amster, 2003). There is currently no published regulatory guidance regarding the cleanup policy at either the state or federal level regarding actions to take following a RDE (Elcock *et al.*, 2004). The current concept of operations identified in the National Response Plan (DHS, 2004) specifies that after events involving radiological terrorism, the Department of Energy (DOE) will be the coordinating agency and will transition to the USEPA,

> "… for environmental cleanup and site restoration at a mutually agreeable time, and after consultation with State, local, and tribal governments, the cooperating agencies, and the JFO Coordination Group." (The JFO is the Joint Field Office.)

If the area of concern is not within federal jurisdiction, the local and state authorities will have the role of protecting life, property and the environment (NCRP, 2001). However, the National Response Plan (NRP) (DHS, 2004) stipulates that for all domestic terrorist events the Department of Homeland Security will have jurisdictional authority. The NRP further stipulates that for a radiological/nuclear event the Department of Energy will be a coordinating agency as will the U.S. Environmental Protection Agency. Lines of communication must be clear and evident between government agencies.

Fragmentation of the information between agencies makes the process of communicating, regulating and risk reduction more complex (NRC, 1989).

Response capability varies from city to city and varies by organization within the city (Bugliarello, 2005). Regardless of the size of the city, no one city can be adequately equipped with the myriad of resources necessary to recover from such an event (Bugliarello, 2005). It is, thus, imperative that resources from the private sector and education be coordinated to support the area affected (Bugliarello, 2005). Although the context of Bugliarello's argument is the urban setting, it can be extrapolated to rural, residential, agricultural and recreational areas as well. A significant weakness identified by exercises conducted by the DHS is the coordination of transportation, pedestrian movement, emergency responders, sheltering and logistics (Bugliarello, 2005). In the event of a RDE, mass evacuation is not likely to be required, but as a demonstration of failure to plan Bugliarello (2005) states, "... no major city worldwide has an effective evacuation plan for the entire city." Kelly (1995) states that failure to plan before an event leads to a dysfunctional response. Further, he states that planning "... provides guidance specific to a possible disaster situation, reduces uncertainties in mounting a response, permits the identification of possible resource requirements and provides data on which to formulate response-funding requirements." The context of the previous claims is for the immediate response, which is not the focus of this study. However, since crisis-management and consequence-management often overlap, and resource availability and allocation are pertinent, these cases are germane.

Part of the reason for the lack of policy and/or guidance is the wicked nature of the problem and the intractability, in general, of dealing with subjects involving nuclear technology and/or radiation (Slovic, Flynn, & Layman, 1991). Rittel and Webber (1973) defined a wicked problem as one that has one or more of the following ten distinguishing aspects.

1. There is no ultimate formulation of a wicked problem.
2. Wicked problems have no stopping rule.
3. Solutions to wicked problems are defined as good or bad rather than true or false.
4. There is no immediate or final test of a solution.
5. Opportunity to learn by trial and error is nonexistent because every attempt counts significantly.
6. The set of solutions is limited and there does not exist a well-described set of permissible operations that might be incorporated into the plan.
7. Every wicked problem is basically unique.
8. Each wicked problem can be considered a symptom of another problem.
9. Incongruities within the problem can be explained in numerous ways and the explanations for these determine the nature of the problem's resolution.
10. The decision maker has no right to be wrong.

Addressing the wickedness of the RDE scenario requires consideration of stakeholder wants and needs, their education via risk communication or formal training and planning and preparation, i.e. development of an adequate approach

to deal with the recovery. Each of these is addressed in more detail in Chapters 4 and 5. This issue is not inconsequential and cannot be resolved quickly or reactively, and this reinforces the importance of developing an approach well before a RDE occurs.

Technical analyses alone can not provide the sole framework from which to solve a wicked problem (Stewart, Walters, Balint, & Desai, 2004). Including the societal and political expectations of all parties involved results in a more balanced risk assessment and includes the desires and fears of the affected populations (Kaplan & McTernan, 1993). According to Renn (1995), the use of expert judgment alone will not provide a policy representative of the public's values.

Developing sound public policy is based on the ability to understand the public's perception of risk (Marris, Langford, Saunderson, & O'Riordan, 1997). The typical layperson and policy-maker base their decisions about risk on their varied definitions. The policy-maker bases decisions on the expected number of fatalities or injuries (i.e. health issues), whereas the layperson has a broader definition and includes much more (Marris, 1997). The concept of risk to a layperson is richer and broader than that of the policy-maker and is typically omitted from the risk assessment (Slovic, 1987). Putzrath and Wilson (1999) argue that the use of a linear no-threshold dose-response curve and its subsequent safety indices might be purely policy driven. However, the NRC has recently reaffirmed the use of this model (NRC, 2005), and it should, therefore, be a consideration when considering and developing the end-state of the recovery.

The final consideration in the plan is to identify a successful remediation before the event occurs (Frantzen, 2002). Remediation or recovery focused on achieving a community value, such as economic, recreational, social, cultural or environmental values, could create controversy (Frantzen, 2002) and, therefore, must be considered and resolved before the RDE occurs. Controversy and misunderstanding tend to reinforce the wickedness of an issue. Identification of the community's values and priorities will be necessary to ensure an acceptable policy is created and implemented. The decisions made can avoid some problems if a common-sense approach considering science, economics and stakeholder values, as well as legal, social and political issues is used (Frantzen, 2002). The solution to the problem is in the hands of those who define the risk for that situation (Slovic, 2001).

Policy, based on science, is itself based on uncertainty (Ruckelshaus, 1983). Laws originating within the USEPA are based on uncertain science, but require a defined level of protection (Ruckelshaus, 1983). The interaction of expert and policy-maker, through the integration of expert judgment and intent to produce useful legislation, is destined to become more important due to the complex nature of economic, social and environmental problems (Renn, 1995).

The public's perception of risk has been shown to affect the priorities and legislative agendas for regulatory bodies (Slovic, 1999). The level of influence public perception plays should be resolved to reduce potential conflict between the scientific and policy areas (Renn, 1995).

The risk communication process can also be a source of wickedness. The NRC (1989) has noted that risk communicators sometimes relate information without relevant data, and this leads to errant conclusions. Misinformation can also lead to a lack of credibility (NRC, 1989), which can fuel the wicked nature of the scenario.

Decisions are based on a risk assessment that provides details regarding potential adverse effects, but also considers the sociopolitical and socioeconomic implications of a decision within the constraints of legal mandates (Suter, Vermeire, Munns, & Sekizawa, 2003a). In planning for a water infrastructure contamination contingency, Allgeier and Magnuson (2004) point out the importance of planning early and beginning at the local level. They note the following, at a minimum must be addressed so that the roles and responsibilities are clearly identified.

1. Who will respond?
2. Who will determine if the threat is credible?
3. Who will collect and evaluate samples and assess the site?
4. Who will make public health decisions?
5. Who will manage remediation?

Critical to the assessment is the development of baseline or background data (Allgeier & Magnuson, 2004).

2.5.1. Citizen/Stakeholder Participation

Stakeholders are societal members concerned with the issues associated with the assessment, and they might be affected by the decisions made as a result of the assessment (Suter *et al.*, 2003a). Stakeholders could be representatives from the following categories (Suter *et al.*, 2003a):

1. Private citizens,
2. Industry,
3. Public interest groups,
4. Property owners, and/or
5. Resource consumers.

A stakeholder, as defined by Sjöberg (2003), "... is a person or actor with special concern and interest in an issue, and may be considered to be concerned either on the basis of self-report or on the basis of observed activities." He further noted that being a stakeholder is a matter of degree and not an all or none proposition. Credible risk management is only possible when there is open participation by all stakeholders (Shrader-Frechette, 1998).

Identification of the pertinent stakeholders early in the planning process is critical to ensuring a successful and acceptable plan (Frantzen, 2002). Frantzen (2002) suggests considering the local political and social structure in the affected area and creating a situation-specific network. This is critical to an effective recovery and has implication in many aspects of the assessment such as risk communication, acceptance of risk management decisions and public reaction immediately following a RDE. Active participation by the stakeholders will

result in better understanding and success of decisions made based on the assessment (Suter *et al.*, 2003a).

In a democratic society, the values and beliefs of the public have a natural priority (Sjöberg, 2003). Political, economic and historical factors could contribute overwhelmingly to acceptance (Wolfe, 1993). These parameters are included in the Level of Impact analysis discussion in Chapter 4. Each is recognized as an essential component of the overall assessment of the impact.

The Citizen Advisory Committee (CAC) is an enduring and ever-present form of public involvement (Lynn & Busenberg, 1995) and has been used in environmental issues for at least 30 years. The CAC is a small group of individuals gathered to represent the ideas and attitudes of larger groups for the purpose of reviewing a proposal, issue or set of issues, but who are not typically given final approval authority over decisions (Lynn & Busenberg, 1995). Lynn and Busenberg (1995) listed benefits of the CAC process as:

1. Educating the decision-maker regarding community attitudes,
2. Educating participants regarding the institutional positions,
3. Providing a forum for citizen involvement in the decision making process,
4. Improving public support for decisions, and
5. Providing a smaller contingent to deal with rather than the entire community.

2.5.2. Precautionary principle and adaptive management policy approaches

Two policy decision concepts, the precautionary principle and adaptive management, have been discussed and proposed as potentially applicable to dealing with wicked environmental problems (Stewart *et al.*, 2004). The literature indicates adaptive management was developed and has been applied to the management of ecosystems in the Everglades and Sierra Nevada National Forest and regarding North American waterfowl (Gunderson, 1999; Stewart *et al.*, 2004, Johnson & Williams, 1999). The precautionary principle is ubiquitous within environmental policy and law (Hornbaker & Cullen, 2003; Sandin *et al.*, 2004; Bodansky, 1991) because it provides a level of conservatism requisite to the protection of the environment and human health.

2.5.2.1. Precautionary principle

The precautionary principle was first applied as a basis for policy and law in the early 1970s in West Germany and was termed *vorsorgeprinzip* or "foresight principle" (Hornbaker & Cullen, 2003). The principle is a basis for "... eliminating, postponing, or modifying an action that might pose a risk to human health and safety or compromise environmental quality." (Hornbaker & Cullen, 2003). However, there is no consensus on exactly what the principle means (Sandin *et al.*, 2004). Precautionary-based approaches imply the "... prudent handling of uncertain or highly vulnerable situations" (Klinke & Renn, 2002), and precautionary behavior is an instinctive reaction to any sudden or unfamiliar intrusion (Starr, 2003).

There is debate, however, on the application of the precautionary principle. The debate centers on the application in events with risk, irreversibility of damage and social costs (Farrow, 2004). Bodansky (1991) argues that the principle is too vague from a regulatory perspective. Others argue that it ignores scientific results and leads to arbitrary regulatory decisions (Cross, 1996). Starr (2003) comments that the precautionary "principle" does not exist and provides no useful input to decision-making. Hornbaker and Cullen (2003) identify three immediate problems when applying the precautionary principle to U.S. environmental issues: 1) a dilemma in the definition of the principle, 2) lack of an accepted framework, and 3) lack of experience unique to the U.S. The current use of cancer slope-factors in the U.S. is based on the linear-no-threshold model which, in turn, is partially based on animal studies. The application of animal studies to define carcinogenic effects in humans is a precautionary approach (Sandin *et al.*, 2004).

2.5.2.2. Adaptive management

The adaptive management approach promotes recurring evaluation and policy and procedural adjustment throughout the course of implementation (Stewart *et al.*, 2004). The approach requires early identification of stakeholders and promotes their integration into the decision-making process (Stewart *et al.*, 2004). Habron (2003) notes that adaptive management is a series of linked, iterative steps consisting of problem identification, brainstorming, model development, hypothesis testing, planning, experimentation, monitoring, evaluation and behavioral change. Each of the above clearly identifies aspects for consideration

when recovering from a RDE and are, therefore, included in the proposed approach discussed in Chapter 4. They speak to the unique characteristics that are expected when recovering from a RDE.

An adaptive process is required when dealing with a RDE because within this scenario surprises or uncertainties are expected (Gunderson, 1999). Habron (2003) commented that one of the key tenets permeating the steps of adaptive management is surprise. Likewise, one of the goals of terrorism is surprise. An adaptive approach is ideal, then for combating the effects of terrorism. One of the types of surprise is "genuine novelty" (Gunderson, 1999). This type might have the most applicability to a RDE. This type of surprise is characterized by a unique situation where little or no experience exists regarding management of the process. Gunderson (1999) notes, however, that the approach will not work if the system or stakeholders are too inflexible; flexibility is a key tenet of the proposed approach discussed later. Stewart *et al.* (2004) stated, "Adaptive management is necessary but not sufficient for coping with wicked problems." In other words, an approach that is solely adaptive will not provide the most effective solution. In the case of a RDE, the approach must be adaptive and flexible. The flexibility needed is defined during the problem formulation of the proposed approach.

Johnson and Williams (1999) identified the lack of well-defined objectives derived from unresolved value judgments about the resources as a major impediment to effective management. Furthermore, adaptive management cannot be used to cope with disagreements over goals and objectives. Iles (1996) noted

the difficulty in implementing this approach lies with the "top down" structure in legislative and administrative agencies.

2.6. Risk Assessment Methodologies

Risk assessment and risk analysis are sometimes used interchangeably. Risk management, however, is the culmination of the risk assessment, data analysis process whereby the risk assessor, manager and other decision-makers synthesize the information presented and determine the best approach to problem resolution. Risk assessment is the technical, scientific portion of the analysis, and risk management is the decision-making aspect based on the risk assessment and any other pertinent information available (Suter *et al.*, 2003a).

The use of a linear-no-threshold dose model results in a conservative estimate of the potential risk and results in higher costs when remediating to currently acceptable levels (Kaplan & McTernan, 1993). The NRC (1983) states that extrapolation in the low-dose range is more than just curve fitting: the plausibility of the effect(s) also must be considered. The use of this model was recently reaffirmed (NRC, 2005).

There are currently two basic domains within which to analyze risks from contaminants: human health and ecological. Within each of these areas are methods involving probabilistic, qualitative and quantitative methods (Covello & Merkhofer, 1993). Risk assessment has been defined as the systematic process for describing and quantifying risks associated with hazardous substances, processes, action or events (Covello & Merkhofer, 1993). The basic steps of risk

assessment have been identified as: 1) release assessment, 2) exposure assessment, 3) consequence assessment and 4) risk estimation (Covello & Merkhofer, 1993). The National Research Council (1983) defined the process within a "risk paradigm" as: 1) hazard identification, 2) dose-response assessment, 3) exposure assessment and 4) risk characterization. Canter (1993) stated the previous four-step process is the traditional method of conducting a risk assessment. The USEPA (1989) classifies the risk assessment process as: 1) data collection and analysis, 2) exposure assessment, 3) toxicity assessment and 4) risk characterization. In general, all risk assessment methodologies fall within one or more of the models or are adaptations thereof.

The final step in the risk assessment process, regardless of the model, is the development of the risk "number". There are generally two methods whereby the risk is estimated: quantitative and probabilistic. The probabilistic approach expresses a probability distribution of risk (USEPA, 2001) and has been credited with providing a more rigorous expression of uncertainty (Covello & Merkhofer, 1993). The quantitative approach, used by the USEPA, expresses the risk as a point estimate as the product of a human intake value and the slope-factor for carcinogenic risks and the quotient of the intake and reference dose for a non-carcinogenic risk (USEPA, 1989). It has been qualified as "primitive and crude" (Molak, 1997). The latter approach is most commonly used due to its simplicity.

2.6.1. Problems with current methods and some recommended solutions

The use of radioactive materials in a terrorist's weapon presents challenges in the response and recovery phase. The use of radioactive material and the disposal of generated wastes has a long history of debate and strong public opinion (Williams, Brown, Greenberg, & Kahn, 1999; Stoffle, Stone, & Heeringa, 1993). The complexity increases when coupled with a terrorist event.

Decisions related to unusual situations, such as those required in the aftermath of a terrorist attack, often require a fundamentally different risk assessment methodology than that traditionally used (Putzrath & Wilson, 1999). Current methods do not adequately incorporate a full range of risks beyond the scientific or probabilistic aspects (NRC, 1994). Some of the additional risks that should be considered are those associated with economic impact, the social acceptance of remediation possibilities and the potential remediation impact, e.g. will the remediation require removal of contaminated media that will significantly decrease the usefulness of the area.

The essence of risk assessment is the application of experience gained from past mistakes to the current situation so as to prevent new mistakes in new situations (Wilson & Crouch, 1987). The present scenario is so unique that this might be difficult. Two cases are noted in this study where lessons learned can be applied to a RDE: Goiãnia and Chernobyl. Lacking historical data from which to draw conclusions about the hazard, one way of dealing with a problem is to consider the situation in parts: calculate the risk from each part and add them together to estimate the risk from the whole (Wilson & Crouch, 1987). This has

some applicability when dealing with multiple contaminants or possibly when dealing with multiple input parameters, such as is the case with a RDE.

Slovic (1999) stated that risk assessment is a subjective venture and represents the blending of science and judgment as well as psychological, social, cultural and political factors. Furthermore, due to the complexities of risk assessment there is a need for a new approach. Risk assessment should involve the public to a greater extent and include the psychological, social, cultural and political factors. Risk assessment is not designed to make judgments, but to illuminate them (Wilson & Crouch, 1987). The risk assessment must include a consideration of perceived risk (Frantzen, 2002) and therefore, must involve stakeholders early so that those perceptions can be delineated.

Suter (2000) noted that the general remedial process that involves a risk assessment is not adequate for emergency response due to the inherently long process. He stated that the application of the existing process would be inappropriate. Reisch and Bearden (1997) provided some interesting statistics for the cleanup of Superfund sites in their report to Congress. They stated the preliminary assessment study takes an average of 95-145 hours to complete. The remedial investigation/feasibility study takes 18-30 months to complete and the remedial design takes an average of 12-18 months to complete. The Congressional Budget Office released a report in 1994 (CBO, 1994) in which it estimated a total cost of $75B to cleanup the, then, 4,500 Superfund sites that then required work. This resulted in an average expenditure of $16.7M per site. This value has implication when considering the applicability of CERCLA to a RDE.

Suter (1995) also noted that a balance between ecological and health risks is not the same for every site based on the current and future land use considerations. In other words, the approach must be flexible and adaptive allowing for the variety of unique and complex issues that are likely to be present following a RDE.

2.6.2. Human health risk assessment

The standard paradigm for human health risk assessment consists of estimates of carcinogen risks and non-carcinogen reference doses (Putzrath & Wilson, 1999). The sole endpoint of a human health risk assessment is a conclusion about the individual health of humans (Suter *et al.*, 1995) and is often done without consideration from other areas. Putzrath and Wilson (1999) contend the current methodology for human health risk assessment must be adapted for the specific characteristics of a given situation. Although this argument is made for traditional risk assessments, it is valid for the case of a RDE. Adaptability and flexibility are key components of assessing the RDE impact. There are many parameters that must be considered in addition to the increased probability of cancer.

The human health risk assessment process is outlined in the USEPA's *Risk Assessment Guide for Superfund* (USEPA, 1989). The USEPA approaches human health risk assessment in a four-step process: 1) data collection and analysis, 2) exposure assessment, 3) toxicity assessment and 4) risk characterization. This is commonly referred to as the "risk paradigm" (Putzrath &

Wilson, 1999, Whittaker, 2004, Mercat-Rommens, Louvat, Duffa, & Sugier, 2005). The USEPA (1989) states the guidance for the remedial process of the HHRA is designed, "… to implement remedies that reduce, control, or eliminate risks to human health and the environment." However, throughout the guidance the focus is clearly on the protection of human health with little indication that the environment is a consideration. This is not necessarily a contradiction. Consideration and protection of human health require that the environmental impact be addressed at least implicitly. Furthermore, the ecological assessment process discussed in the next section at least partially addresses the human health aspect by virtue of its more complete framework.

2.6.3. Ecological risk assessment

Ecological risk assessment was derived from human health risk assessment (Suter, 2000). The purpose of the assessment is to provide a technical basis for managing a release of contaminants posing a risk, the breadth of which depends on the scope of the decision-maker's concerns (Suter, Munns, & Sekizawa, 2003b). The process is complicated because it must consider numerous populations, communities and ecosystems (Suter *et al.*, 1995).

Because ecological health is not as well defined as human health there are a wide range of meanings (McDaniels, Axelrod, & Slovic, 1995), and quantifiying the ecological risk is, therefore, difficult.

The USEPA (1997a) provides an eight-step process for conducting an ecological risk assessment:

1. Screening level (site visit, problem formulation, toxicity evaluation),
2. Screening level (exposure estimate, risk calculation),
3. Problem formulation (toxicity evaluation, conceptual model, assessment endpoints, hypotheses),
4. Study design,
5. Verification of field sampling design,
6. Site investigation and data analysis,
7. Risk characterization, and
8. Risk management.

In general, the ecological risk assessment has greater applicability to most scenarios because it was developed 1) to deal with a wide range of environmental issues, 2) to describe the nature and role of the environment in the risk process, and 3) to explicitly address the identification of the endpoints (Suter *et al.*, 2003a).

A recent proposal suggests using a tiered approach to environmental (or ecological) risk assessment. Pollard *et al.* (2002) suggested that the framework presented in Figure 2.1 be used because it provides a level of proportionality not offered by other frameworks. A tiered approach allows for varying degrees of sophistication based on the complexity of the problem and the understanding of those involved in finding a solution (Pollard *et al.*, 2002). It represents an iterative approach common to most assessment methods, and, is one that is essential in assessing the impact from a RDE. Additionally, this model includes parameters not routinely included in human health risk assessments, such as

economics and social issues. It provides a starting point for the development of the Level of Impact analysis presented in this study.

2.6.4. Integration of ecological and human health risk assessment

By combining the ecological risk assessments (ERA) and human health risk assessments (HHRA), both humans and the ecology can be better protected (Suter *et al.*, 2003a). Suter *et al.* (2003a) have proposed an integrated approach consisting of three major components. The first, problem formulation, requires the identification of goals, objectives, scope and activities of the assessment. The second component is the analysis phase. This phase includes the data collection, modeling and definition of effects on humans and ecological receptors. The final step, risk characterization, is a synthesis of exposure and effects to estimate a risk value.

The integration of ERA and HHRA has been proposed for use in environmental impact assessments as well (Canter, 1993). The advantage of integration is seen as providing a multidisciplinary approach (defined here as involving individuals from different backgrounds) directed toward effective resolution to environmental problems. The idea of integration throughout environmental management was explored by Toth and Hizsnyik (1998). They identify its origin as an application to the problem of world-wide acid rain deposition. They further identify the role of integration as essential when the desired outcome is a policy decision. In fact, they note the most succinct definition of integrated environmental assessment is an interdisciplinary and

policy-oriented synthesis of scientific information with some qualifications. Schneider (1997) stated that integrated assessments are constructed primarily to address "real world" problems that span many disciplines.

Further analysis of applying the integrated approach was conducted by Rotmans and Dowlatabi (1997). The two proposed that an integrated assessment is an interdisciplinary process (multidisciplinary as defined in this study) that combines interpreting and communicating knowledge from diverse scientific disciplines. This results in a method whereby the cause-and-effect interactions can be evaluated. They further note that the assessment must have two characteristics: one, it should add value and two, it should provide useful information to the decision-makers. Value added could be in the form of a more complete assessment, saving resources or reducing the time to complete the assessment.

Failure to integrate the two types of assessments can lead to improper management of resources and misinformation, thereby causing inappropriate decision-making (Suter *et al.*, 2003b) and adverse, long-term effects to either humans or the environment. The USEPA (2005) noted the advantage of integrating assessments as a way of saving both time and money.

There is a duality inherent in risk ((Klinke & Renn, 2002). The social and physical aspects of the hazard must be integrated in the risk assessment (Fiorino, 1989). Klinke and Renn (2002) suggest the physical and social elements be measured independently unless there is evidence of a link. Psychological and social parameters should be evaluated and not considered a modifier of the

physical hazards. They further explain that physical components that initiate social concern should also be assessed. This will ensure the public's concerns are legitimatized (Klinke & Renn, 2002).

The German Government's Advisory Council on Global Change (WBGU) conducted a study based on expert and public concerns regarding the evaluation of risk (WBGU, 2000). Based on their results the following nine criteria were identified as representative of both expert and public concerns (Klinke & Renn, 2002).

1. Extent of damage,
2. Probability of occurrence,
3. Uncertainty,
4. Ubiquity,
5. Persistency,
6. Reversibility,
7. Delayed effects,
8. Violation of equity, and
9. Potential of mobilization.

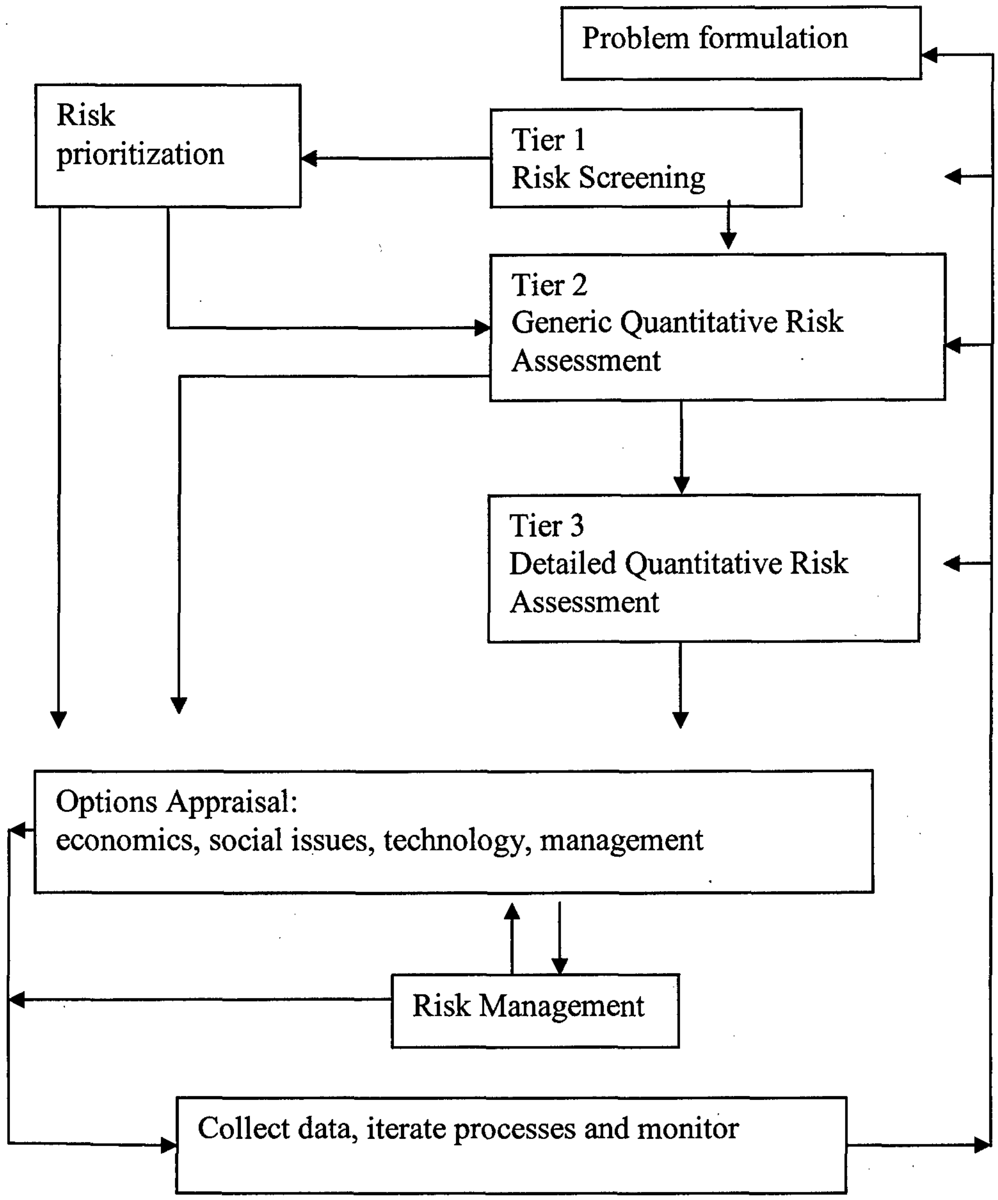

Figure 2.1. Framework for environmental risk assessment (after Pollard *et al.*, 2002).

The USEPA (2003), in an attempt to further perpetuate the idea of integration, recently published its *Framework for Cumulative Risk Assessment,* in which they define cumulative risk assessment as,

"An analysis, characterization, and possible quantification of the combined risks to health or the environment from multiple agents or stressors."

They acknowledge that stressors do not have to be chemical in nature but can be from other types of sources. In this framework they identify the three main phases of cumulative risk assessment as 1) planning, scoping and problem formulation, 2) analysis and 3) risk characterization. The intent of this framework is to encompass the variety of stressors that could affect the risk management decision, thus allowing for both ecological and human health issues. They identify that typical risk assessments do not encompass all factors, and some form of integration or cumulative assessment could be advantageous in some cases.

2.7. Risk Perception

It is generally agreed that the physical effects from a RDE in a body of water will be negligible (Ring, 2004; Elcock *et al.*, 2004; NCRP, 2001) due to the large quantity of radioactive material required to contaminate such a volume of water to a level whereby adverse biological effects can be observed. The most significant effects, then, will be social and economic (Elcock *et al.*, 2004). Likewise, the doses of radiation expected to have an ecological impact are orders of magnitude higher than those expected to result from a RDE (Jones, Domotor, Higley, Kocher, & Bilyard, 2003). Ford (1998) also emphasized this point by stating "The

psychological and political effects of RDD use are not well understood and are potentially more significant than the lethality effects of such use."

Once the public is aware of a release of radioactive material, the release is likely to cause widespread panic (Steinhausler, 2003). The accidental release of Cesium-137 in Goiänia, Brazil, in 1987 resulted in approximately 112,000 individuals being surveyed for contamination (Steinhausler & Wieland, 1998), although only approximately 300 individuals had evidence of any contamination; four individuals died from radiation-induced injury (Rosenthal, de Almeida, & Mendonca, 1991).

The limited understanding and knowledge of radiation by the public, in addition to the inability of the human to sense exposures, can lead to an increased negative perception of radiation (Maerli, 2003) and, therefore, contributes to a general fear of radiation. Maerli (2003) further noted that the threat of the spread of radioactive material makes its misuse more attractive because of the fear of radioactivity. Van Moore (2004) identified the most prominent, latent effect from use of a radiological weapon as psychological rather than physical, as did Geelhood and Wogman (2005).

Freudenburg (1988) noted the psychosocial impact of the accident at Three Mile Island in 1979. (This case is often cited as an example of public reaction following a radiological or nuclear event and can be used as an estimate of the expected effect following a RDE.) Although minimal radioactivity was released, there were reports of significant mental health issues. The effect of this incident was mistrust by the public of those involved in nuclear technology and a more

entrenched fear of radiation. Out of the clandestine origin of its development, nuclear power (radiation) has emerged as a perceived high-risk endeavor. Borne from the memories of Hiroshima and Nagasaki are images of "… death, destruction and annihilation" (Ring, 2004). People have "frightening historical associations" with radiation as a result of the use of nuclear weapons in Hiroshima and Nagasaki and the nuclear reactor accident at Chernobyl (NCRP, 2001).

Deployment of a RDE is ideal, from a terrorist's perspective, because it plays on the fears and perceptions of the public (Johnson, 2004; Ring, 2004). Members of the general public are unaware of the real radiobiological effects of ionizing radiation and base their impressions and fears on dread and the unknown associated with radiation (Johnson, 2004; Slovic, 1987). People fear the "invisible toxins" such as radiation, in part, because they cannot sense its presence (NCRP, 2001). Tucci and Camporesi (2003) comment that the expected biological hazard will be manageable but the effect as a result of the fear and terror of radiation will magnify the effect in the population.

The psychometric paradigm (Slovic, 1987) has been used by many authors in identifying underlying themes in risk perception (Lion *et al.*, 2002; Sjöberg, 2000; McDaniels *et al.*, 1997; Marris, *et al.*, 1997, Branch, Orians, & Horton, 1993). The primary factors underpinning risk perception are "dread risk" and "new/unknown risk" (Lion *et al.*, 2002). Due to the nature and recent media attention of terrorism within the U.S., a RDE might be classified as a "new/unknown risk". Slovic (1987) elaborated on the concept of the

psychometric paradigm whereby events that are involuntary and uncontrollable provide an element of dread, and elicit the highest perception of risk. To a considerable extent this is regardless of the actual, quantifiable risk. Nuclear risks (e.g. RDE) are perceived as unknown and can have a significant ripple effect throughout a community (Slovic, 1987). The psychometric paradigm attempts to identify characteristics that influence a person's perception of risk (McDaniels *et al.*, 1995).

Sjöberg (2000) identified the beginning of risk perception research with the advent of the nuclear debate of the 1960s. Persons who are in favor of nuclear power generally see the risk from radiation as lower than those who are not in favor of nuclear power (Sjöberg, 2000). Risk perception appears to be a central theme in understanding the decisions and statements of policy makers regarding environmental issues (Sjöberg, 2000).

In a recent study, Sjöberg (2003) found that those selected as typical stakeholders do not always represent the views of the public; in many cases they are more extreme in their positions. Branch *et al.* (1993) stated that people do not base their decision solely on the presented risk; rather, they evaluate the acceptability of the entire situation. The layperson places great weight on catastrophic potential (Fischhoff, 1995), and events involving radiation are seen as potentially catastrophic.

The NCRP (2001) states it is imperative for those developing response and recovery plans and policies regarding radiological terrorism to "... recognize the centrality of social and psychological issues." This is due, in part, to a terrorist's

goal of inflicting psychological harm (NCRP, 2001). The NCRP further reinforces the importance of perception in their discussion of communication. They state the communication approach must be, "... informed by an awareness of people's fears and concerns and that effectively conveys the information needed to protect health and safety." A recovery based solely on a numeric cleanup goal is likely to be faced with resistance from stakeholders.

Hart (2002) stated that the effectiveness of a dispersal device will be based on how it is viewed and treated by society before and after the event. The effectiveness of the recovery will be enhanced or hampered by public officials and professionals. The contamination, or its threat, has been demonstrated to substantially impact at all levels: individual, family and community (NCRP, 2001).

The attributes listed below are seen as high risk and of greater concern to the general public from a perception perspective (Branch *et al.*, 1993) and can be attributed to a RDE. Each of these must be addressed to some level in the assessment. It is plausible the perception of the risk will exceed the actual risk, but that does not make the recovery any less difficult. If the following issues are not addressed, resolution during the problem formulation phase is not likely.

1. The hazard (i.e. radiation) has potential for causing genetic defects (Slovic, 1987),

2. There is uncertainty regarding the nature of the hazard and its effects due to extrapolation from high doses and high dose rates (Covello, 1983; Mitchell, 1992),

3. Exposure to the hazard is involuntary (Slovic, 1987),

4. The hazard is invisible and undetectable by human senses (Slovic, 1987), and

5. No applicable standards exist regarding how to deal with it (Mitchell, 1992).

Because its impacts are involuntary, terrorism has been rated as having a higher than normal perception of risk (Slovic, 1987) and has been identified as a new "species" of trouble (Slovic, 2002). Others have found the psychological impact from terrorist attacks to be significant and to contribute to post traumatic stress disorder (Bugliarello, 2005; Schlenger *et al.*, 2002).

2.8. Risk Communication

"Every year (or, perhaps, every day) some new industry or institution discovers that it, too, has a risk problem. It can, if it wishes, repeat the learning process that its predecessors have undergone. Or, it can attempt to short-circuit that process, and start with its product, namely the best available approaches to risk communication" (Fischhoff, 1995). A critical challenge of the policy makers and others involved in the response and recovery of a RDE is to develop a risk communication strategy that takes into account fear and concerns of the public and that adequately and effectively conveys the needed information (NCRP, 2001). Furthermore, individuals or organizations responsible for communicating the risk should understand the way people think about the perceptions (Lion *et al.*, 2002). Becker (2004) noted that in the event of a radiological terrorist event an

effective risk communication plan could "… be one of the most important actions that health, safety, and emergency management agencies can take to help people take appropriate self-protection measures, limit adverse social and psychological effects, maintain trust and confidence, and reduce morbidity and mortality."

In a study sponsored by the Centers for Disease Control and Prevention (CDC), Becker (2004) reported the results of findings regarding the "Pre-Event Message Development Project." This project was undertaken to study the role of risk communication during a terrorist event involving chemical, biological and nuclear/radiological weapons. The intent of this study was to determine the type of information needed or wanted by those affected by the weapon and its methods of dissemination. The results will be used to develop pre-written messages for release following a terrorist event involving one of the aforementioned weapon types. Results of the study indicate the following are crucial aspects requiring consideration when developing a successful risk communication plan.

1. Public reaction to radiological releases and weapons is generally negative.

2. People want to know the basics of radiation, i.e. what is it and how it affects them.

3. The use of technical terms can be confusing.

4. What are the actions to take to ensure self and family safety?

5. The government is not likely to release all of the information after an event such as a RDE.

6. There are only a few individuals that are considered credible or trustworthy (e.g. fire chief, sheriff, U.S. surgeon general, local weatherman).

Release of the messages, however, will not occur until an event has occurred. One of the goals of the project is to pre-identify the concerns of those potentially receiving the message and to aid in the anticipated request for information. As presented in Chapter 4, the proposed Level of Impact approach identifies the need to pre-release information so as to better prepare the public should a RDE occur.

Fischhoff (1995) identified what he calls "developmental stages in risk management." These are the different approaches to risk communication previously used.

1. All we have to do is get the numbers right.
2. All we have to do is tell them the numbers.
3. All we have to do is explain what we mean by the numbers.
4. All we have to do is show them that they've accepted similar risks in the past.
5. All we have to do is show them that it's a good deal for them.
6. All we have to do is treat them nice.
7. All we have to do is make them partners.
8. All of the above.

Communication of the actual risk to humans and the environment is complicated. Simply reporting numbers is often ineffective and confusing. Therefore, the communication of the risk must involve the appropriate number in

the form that will be the most meaningful to the audience (Fischhoff, 1995). Treating the audience with respect and honesty is essential in communicating (Fischhoff, 1995). Trust has been linked to the perception of risk; a lack of trust leads to a perception that risks are higher than actual (Slovic, 2001). A lack of trust can also lead to the dismissal of the risk assessment (Slovic, 1999).

Risk has different meaning in different contexts. Discussing risk to the individual is different than providing an estimate of risk to a family (Sjöberg, 2000). The message must, therefore, be adjusted to the target audience. The manner in which the presentation of risk is framed will greatly influence acceptance by an audience (Slovic, 2001).

There is no universal set of rules for describing risk (Slovic, 2001). Danger is real, but risk is a socially constructed representation (Slovic, 2001). The broad conception of risk by the public (Slovic, 1999) requires the communication plan also be broad and requires the risk assessment approach to consider all parameters.

The NCRP (2001) notes that a successful consequence-management communication plan achieves trust and credibility. Slovic (1999) identified four factors that influence trust when dealing with the public. These are essential to developing an effective risk communication program. Negative events are defined as trust destroying, while positive events are trust creating.

1. Negative events are more visible than positive ones.
2. Negative events carry greater weight than positive events.

3. Sources of trust-destroying news tend to be seen as more credible than trust-creating news.

4. Distrust tends to perpetuate distrust.

The release of information in a timely and accurate manner is vital. However, deciding what information is releasable and when must be consistent with national and operations security (NCRP, 2001). Differences between federal, state and local authorities could create discord when determining what information is to be released and when (NCRP, 2001). Trust and confidence are important factors in communicating effectively with the public (Slovic *et al.*, 1991). When information is presented by persons not known by the local community, residents might resist accepting the information as accurate (Branch *et al.*, 1993).

A study conducted by Lion *et al.* (2002) demonstrated that when people wanted information regarding an unknown risk the following were the questions they asked.

1. What is the actual risk?

2. What are the consequences?

3. Are the risks and consequences controllable?

4. How are people exposed to the risk?

When information is released it should be conveyed in a manner that does not create unwarranted fear. The goal is to assure the public that actions to be carried out after a terrorist event are appropriate and based on known information (NCRP, 2001).

The values and beliefs of the decision-makers must also be considered when developing a risk communication plan. Most risk perception research has been focused on the point of view of the public and has not considered the manager's perspective (Chess, 2001).

Risk communication is an essential, interactive process in which information about the risks is exchanged (NRC, 1989). A model of risk communication proposed by Rohrmann (1998) outlined the complexity of the process by noting the interaction of personal evaluation and prior attitudes. Bhatti (2001) noted there are three basic aspects to risk communication: originating, communicating and receiving information. Within these aspects the stakeholders play a significant role in each aspect with their respective cultures weighing heavily on the communication process. Enders (2001) further elaborated and stated the communication process is dependent on socio-economic factors as well.

To elicit behavioral change the following steps are involved (Enders, 2001).

1. Attention,
2. Comprehension,
3. Interpretation,
4. Confirmation,
5. Acceptance,
6. Retention, and
7. Behavioral change.

2.9. Summary

The literature reviewed herein demonstrates clearly the impending and plausible threat of a RDE, the lack of clear guidance regarding the recovery and remediation following the event and some of the important aspects regarding the effects of a RDE. Additionally, the literature summarizes the important aspects of perceived risks within the context of a radiological release, nuclear technology or terrorism. Acute human health impairment or ecological effects are not expected to result from a RDE within a large volume of water due to the extremely large concentrations of radioactive material required for water release, but due to the perceived risks, negative social and economic effects are highly anticipated. An integrated approach, flexible and adaptable, is needed to address the issues associated with a RDE.

CHAPTER 3

METHODS

3.1. Introduction

The National Response Plan (NRP) is the governing guidance regarding response to domestic terrorism (DHS, 2004). As such it designates the U.S. Environmental Protection Agency (USEPA) as the lead agency for environmental recovery and remediation following a radiological terrorist event. Since reaction time must be quick, the USEPA is almost certain to use previously developed approaches and methodologies for evaluating the risk from radiological contamination that might be present in the aftermath of a radiological release. However, the risk assessment approaches utilized by the USEPA are insufficient for a response to a radiological terrorist event. Likewise, there is inadequate guidance directing the lead agency responsible for the remediation regarding the approach to the recovery phase of a radiological dispersal event (RDE). The approach proposed in this dissertation addresses the inadequacies of current policy based on a unique approach to risk assessment and impact analysis. The approach will assist decision-makers in making appropriate decisions and directing the response in an efficient manner.

Typical ecological and human health assessments require the significant expenditure of temporal and financial resources. Once the crisis-management

phase has ended, the response and recovery of the area will likely be the responsibility of local and state agencies with the help of a federal agency such as the USEPA. The cost of cleanup and restoration can be significant and can quickly overextend a local government and economy. An effective response begins with the quick actions only available if a plan has been developed before an event occurs. Time is critical following any terrorist action. An immediate response provided by the responsible organizations will engender greater trust and support by the stakeholders, whereas a delayed and possibly muddled approach will degrade or destroy any trust the public has in the responding agencies. A RDE has inherent social and political implications due to the use of terrorism coupled with a radiological device. Both ecological and human health approaches provide applicable and appropriate strategies for dealing with a RDE, but if applied independently and in the context for which they were developed, they are not adequate. Recent calls for integrated approaches to handling "typical" environmental issues have been noted (Suter *et al.*, 2003a; Toth & Hizsnyik, 1998; Schneider, 1997). The approach presented herein is a comparison of the existing methods, and is an approach integrating the two types of risk assessment to produce a tool that can be used to address the multiple risks associated with a RDE. It is unique, and as of yet, untried, for the scenario presented.

3.2. Comparison and Integration of USEPA Ecological and Human Health Risk Assessment Methodologies

Two common frameworks within which risk assessments are conducted are the human health and ecological methodologies. In an attempt to develop a conceptually efficient and integrated approach to deal with a RDE, the two frameworks presented by the USEPA will be compared. The National Response Plan (DHS, 2004) designates the USEPA as the lead agency for response and recovery following all domestic terrorist actions. As such it is anticipated the USEPA risk assessment will, by default, involve the use of their two current approaches. In this dissertation, the unique aspects of a RDE, e.g. public perception regarding radiation, will be integrated into a risk assessment approach that synthesizes the two current USEPA approaches to provide a coherent, integrated approach.

The two USEPA approaches will be methodically compared and analyzed as follows:

1. The two approaches will be presented in their general form.
2. Similarities between the two will be identified.
3. Differences will be identified.
4. Identification of any redundant or unnecessary steps, with respect to a RDE, will be noted. Also, steps will be added, expanded, simplified or modified as necessary.
5. Based on Step 4, the results will be integrated.
6. Data requirements will be identified for pre- and post-event.

7. Additional factors such as societal and economic considerations will also be considered and incorporated into the Level of Impact (LOI) analysis.

The resulting integration of methodologies, with consideration of other factors such as those noted in item 7 above, will lead to the development of an equation termed the Level of Impact equation. This equation, with defined parameters, will provide a mechanism whereby all factors affecting a region can be considered and weighted, as deemed appropriate, to determine the overall effect to the region following a RDE. This approach presents a new framework within which a RDE can be evaluated.

3.3. Evaluation of Current Policy

There is no specific governing directive or policy regarding the environmental evaluation following a RDE. Speculation from some authors (Elcock *et al.*, 2004) indicates that there could be a number of directives and/or agencies which the government might turn to by default. Because the USEPA will be the lead agency for environmental recovery following a RDE it is reasonable to assume they will employ existing legal direction for their response. The Comprehensive Emergency Response, Compensation and Liability Act of 1980 (CERCLA) (P.L. 96-510) might, then, be the default directive. In addition, there are a number of Presidential Decision Directives (PDD) and Executive Orders (EO) which dictate that there be a coordinated federal response and recovery to mitigate environmental consequences from a radiological terrorist event. Although these

directives are important by virtue of the legal requirement to conduct recovery and response, they will not be evaluated explicitly since they provide no direction as to how the assessment should be conducted. Therefore, based on the analysis of CERCLA, USEPA risk assessment methodologies, and available risk communication plans and policies pertinent to terrorism and radiological releases, policy recommendations specific to a RDE will be developed and presented.

3.4. Evaluation of Current Risk Communication Approaches with Respect to Terrorism and Negative Environmental Impact

The risk communication plan is critical both before and after the RDE. Vital to this plan are considerations of the appropriate material to be presented, the timeliness of the message and the credibility of messenger. Based on published plans, suggestions and guidelines, an overview of appropriate risk communication information for pre- and post-RDE will be presented. The perception of risk from radiation is an essential consideration, and this will be addressed.

3.5. Justification

The approach presented herein is taken for the following reasons.

1. The Department of Homeland Security (DHS) has identified that the USEPA will be the lead agency following the Department of Energy's initial response to a radiological terrorist attack (DHS, 2004). It is, therefore, reasonable to assume that the USEPA will use their currently published and available methodologies. Development of a new approach

during or immediately following a RDE would be costly in terms of financial expenditures for mitigation and remediation due to the possibility of a protracted response, deterioration of public trust due to slow response time, reduction in stakeholder acceptance of a plan developed in a reactionary mode, decrease in the effectiveness of risk communication, increase in public fear or, possibly, panic.

2. There are no published models, plans, policies or guidance for a response to a RDE within a watershed.

3. A logical, methodical evaluation and judicious improvement to the current, scientifically accepted approaches should, by extension, result in a reasonable, logical approach.

4. The methods presented in this study are applicable to other situations involving chemical or biological terrorism, and could be so for industrial or transportation accidents or natural disasters.

3.6. Limitations of the Study

This study has obvious limitations. First, there is no study group from which data can be obtained to determine the efficacy of the proposal. Second, policy recommendations designed for response to a RDE can not be tried prior to an event. Third, there are no existing models whereby this approach can be validated or simulations can be run. Fourth, this scenario is, admittedly, a low probability event. The direct human and ecological health effects from such an event within a large body of water are likely to be negligible. However, it is plausible that

there could be localized points with concentrations of radioactive material of significance which could lead to biotic detriment. The most significant effects, owing to the presence of radioactive material and the method of delivery, i.e. terrorism, are likely to be social, political, psychological and economic.

CHAPTER 4

DISCUSSION OF INTEGRATED ASSESSMENT APPROACH

4.1. Introduction

In our world today, we must, to the best of our capabilities, be prepared for any and all circumstances involving terrorism. We are mandated through various executive orders, presidential directives and statutes to ascertain our vulnerabilities and to be prepared for such circumstances. Furthermore, some authors (Elcock *et al.*, 2004; Conklin, 2005) discuss the issue of cleaning up after a radiological terrorist event from the primary perspective of establishing cleanup levels and the myriad issues this presents. There are no consensus standards regarding safe cleanup levels because there are inconsistencies in the approaches federal agencies use to determine a safe level (Elcock *et al.*, 2004). Conklin (2005) noted that the Department of Homeland Security established a working group in 2003 to resolve these issues, and the working group was tasked with developing cleanup standards. While these are certainly important and must be discussed, the more significant aspects are the framework under which the risk assessment is conducted and how the impact of the event is assessed. If these two issues are resolved, the stakeholders, including local decision-makers and state and federal legislators, can use the results of the pre-assessment and post-

assessment to develop appropriate cleanup standards as well as to assess and address socioeconomic and perception aspects of a RDE.

It is not conceivable to expend valuable resources for preparation of a pre- and post-event recovery plan for each individual contingency. It is, therefore, critical to develop a methodology that has applicability to many circumstances. Conklin (2005) noted the application of a "number", i.e. one cleanup goal or value for application to all scenarios, is inadequate and a *process* which encompasses the breadth of issues expected after a radiological release is more appropriate. The approach presented herein provides such an option. It will have an associated financial cost, but the application to other types of terrorist acts involving biological and chemical releases or even industrial accidents makes the cost acceptable. Furthermore, the framework must encompass the complexity of radiological terrorism by approaching it from multiple perspectives. The approach presented includes aspects from disaster management, emergency management and environmental (ecological and human health) risk assessment. It is proposed that an integrated, planned approach that begins well before the release of any radioactive material will provide the most effective approach to combat the effects of this type of release.

Some of the advantages of the proposed, integrated approach model are:

1. The increase in site monitoring (see Section 5.3.4) will provide evidence of chronic change over time for the area monitored. This will provide critical information regarding the verification and eventual assessment of a release.

2. The process is useful and applicable to other circumstances. This approach can be applied to other forms of terrorism such as chemical or biological releases. The cost of implementing for one contingency will provide a mechanism for planning for other potential events.

3. The process forces discussion and interaction between identified stakeholders (residents, local officials, policy-makers at state and federal levels) at an early stage. Discussion initiated early and within the appropriate groups will have a better chance of acceptance. Early identification and incorporation of stakeholders' views is the prescribed approach presented in much of the literature.

4. The early and frequent interaction between stakeholders serves to educate all involved. Education is a key to overcoming some of the perceived risks associated with radiation and terrorism.

5. Pre-assessment during the pre-event phase will provide time for consideration of the end-state should a release occur. Rather than attempting to determine cleanup goals after the event has occurred, during the crisis phase, the goal(s) can be determined *a priori*, be evaluated and be agreed upon by the stakeholders considering all aspects pertinent to the region affected.

6. The conceptual model integrates ERA and HHRA within the context of a RDE. The resulting assessment (not tested in this study) is expected to be holistic, reduce redundant efforts and reduce wasting of resources.

7. The potential legal disconnection which will be a significant factor in the cleanup after the RDE is identified and discussed with possible alternatives.

4.2. Integrated Approach with the Level of Impact Analysis

4.2.1. Why current risk assessment approaches are inadequate for a RDE

The current methodologies for conducting ecological and human health risk assessments require long time periods for public comment, committee discussions and data accumulation. The steps in conventional assessments (Figure 4.1) can take months or years before a decision is made and action is taken to remediate the affected area. In fact, the USEPA's published goal, defined as a "streamlined approach", is to accomplish the remedial investigation/feasibility study (discussed below) in 18 months at a cost of $750,000 to $1M (USEPA, 1989). All of these, for a "typical" risk assessment of a hazardous waste site might be appropriate and needed. However, immediately following a RDE the issue most pressing is the effective, immediate and appropriate response by the local, state and/or federal agencies responsible for the recovery of the area. Suter *et al.* (2000) clearly point out that during an emergency response the general process for assessment and remedial action is not appropriate due to the length of time the process takes. The currently accepted process for risk assessment coupled with the significant, expected expenditure of temporal and financial resources would likely delay the response, could add to the panic expected during a terrorist attack involving radiological materials and foster an environment of distrust between government

agencies and the public. Inaction could also allow the spread of the contaminant into larger areas that could lead to a more technically difficult and expensive remediation.

Ecological and human health risk assessments (ERA and HHRA) are not typically done in concert and data regarding exposures to ecological receptors is not integrated with exposure assessments to human receptors (Munns *et al.*, 2003; Suter *et al.*, 2003b; Cirone and Duncan, 2000). An integrated approach can improve the quality and efficiency of the assessment by linking the data for the two assessment types and by providing a more holistic and coherent view of the process (Suter *et al.*, 2003a; Munns *et al.*, 2003). This approach can lead to a more thorough assessment but, if left to be planned and conducted after the event, might not be accomplished within a useful time period. A model which provides the framework for such integration will result in a more efficient process from the standpoint of resource utilization. The model developed and presented herein provides such a framework.

Current methods are reactionary, i.e. they are based on evaluations of existing hazardous waste sites instead of developing sites, such as those that occur during accidental releases, with sometimes undetermined or unclear future land use determinations. The process is lengthy and expensive. In the event of a terrorist attack any action(s) that can be proactively conducted will reduce the intended effect(s) of the incident, e.g. creation of panic and disruption. Actions in advance of a possible attack will reduce public confusion and fear and incur lower temporal and financial expenditures, should the attack occur.

Risk communication plans are not currently an integral part of a risk assessment, but typically are developed once the assessment is completed. The communication of the risks and proposed actions usually follow after the best course of action has been determined, with limited input from the non-scientific population and constrained by existing laws and regulations. Often, plans are developed one-dimensionally; formulated around the scientific perspective providing myriad tables, charts and numbers. The ideal communication plan is tailored for many audiences, with varying levels of fact-based information and delivered through a variety of media, thus providing the widest dissemination of the most accurate information available.

The inclusion of stakeholder input has long been the credo of risk assessors and government agencies alike. Never before has their involvement been more needed and appropriate. But, identifying and contacting appropriate stakeholders is a time-consuming process. Left to the post-release phase, many stakeholders, and certainly their valuable input, are likely to be omitted. Conklin (2005) notes that there is little time to obtain stakeholder involvement once an event has occurred, and he is correct. This should be conducted well before the event occurs.

It was noted by Toth and Hizsnyik (1998) that current assessment methods do not involve the policy-makers early enough nor do all of the steps in the risk assessment and remedial action obviously contribute to the final goal. They state that under these circumstances an informed response is "practically impossible." The proposed model, which initiates the assessment well before the event, allows

for, and indeed, calls for the inclusion of all appropriate stakeholders so that policy, scientific and socioeconomic issues can be resolved.

A deficiency in the assessment process was noted by some (Conklin, 2005; Elcock *et al.*, 2004). The Consequence Management, Site Restoration, Decontamination, and Cleanup Subgroup of the Working Group on RDD Preparedness were tasked with developing guidelines regarding early-to-intermediate response and final cleanup following a dispersal device. The release of the guidance was delayed for several months beyond its expected release date of early 2005 due to the complexity of the issue. A draft of the recommendations was released on 3 January 2006. The focus of the report was developing Protective Action Guides (PAGs) or allowable radiation dose limits for individuals involved in early-to-late phases of the recovery following a RDE. It does not stipulate legal limits but, rather, recognizes the unique and varied nature of a RDE and recommends that a process be developed and implemented whereby an overall assessment of the impact can be conducted.

4.2.2. Integrated approach

The general approaches presented in the literature for conducting a human health risk assessment (HHRA) follow the National Research Council's "risk paradigm" of hazard identification, dose-response assessment, exposure assessment and risk characterization (NRC, 1983). The USEPA methodology is similar, and is, in fact, based on the NRC approach, but it identifies the USEPA's four-step process as data collection and analysis, exposure assessment, toxicity

evaluation and risk characterization (USEPA, 1989). These four general steps are themselves composed of multiple steps such as site visits, characterization, project scoping and risk management. A conceptual view of the HHRA is provided in Figure 4.1.

The HHRA is mandated by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (Title 42, USC, Sections 9601-9675), as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. Within CERCLA is the National Oil and Hazardous Substances Pollution Contingency Plan (Title 42, USC, Section 9605) (National Contingency Plan or NCP). These statutes provide the overriding authority under which the USEPA conducts the human health risk assessment program. The following is a brief overview of the HHRA process for Superfund sites and is expected or assumed to be the process followed after a radiological terrorist event.

The assessment process is conducted under the framework of a Remedial Investigation/Feasibility Study (RI/FS). Within this framework are three basic components: the baseline risk assessment, the refinement of preliminary remediation goals and remedial alternatives risk evaluation (USEPA, 1989). The purpose of the RI/FS is to evaluate the potential for adverse effects to humans if no action at the site is taken and to determine the best option for removing or limiting the risk. The site is characterized with regard to the location and health implications of a contaminant through the development and implementation of a sampling and analysis plan. Inherent in this plan is the evaluation of background data, or naturally occurring or existing levels of the contaminant. The presence or

absence of the contaminant and, therefore, the estimated risk, is determined, to a large degree, by whether or not the contaminant is present at concentrations at or above background levels. The baseline risk assessment is conducted during the site characterization. The results of the risk assessment are used to determine the extent of any contamination, the possible health effects from the presence of the contaminant and identification or modification of remediation goals, i.e. cleanup concentrations.

The feasibility study (FS) is conducted concurrently with the site investigation. The FS is a process whereby the various remedial options are evaluated based on the following nine criteria (USEPA, 1989).

1. Protection of human health and the environment,

2. Compliance with Applicable or Relevant and Appropriate Requirements (ARARs),

3. Long-term effectiveness and permanence,

4. Reduction of toxicity, mobility or volume strength through treatment,

5. Short-term effectiveness,

5. Implementability,

6. Cost,

7. State acceptance, and

8. Community acceptance.

Although the remedial options are not specifically addressed in this study, a consideration of them is necessary so that a value can be assigned to the cost of remediation, C, parameter in the LOI analysis (discussed later).

The Ecological Risk Assessment (ERA) approach for Superfund sites is published in *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (USEPA, 1997a). The framework identified herein is based on an eight-step process (Figure 4.1) consisting of two screening levels, problem formulation, study design and data quality objectives, verification of field sampling design, site investigation and data analysis, risk characterization and risk management. The intent of this approach is to provide consistency and a scientifically defensible result (USEPA, 1997a).

The general framework for ERA was modified in 1998 in *Guidelines for Ecological Risk Assessment* (USEPA, 1998) and is a modification of the previous *Framework for Ecological Risk Assessment* (USEPA, 1992). The 1998 guidance is simplified by design and consists of problem formulation, analysis and risk characterization, which inform risk management (Figure 4.2). Similarities between the two approaches are shown in Figure 4.2 by connecting lines. Because the ERA was initially based on the HHRA approach it is expected that some steps are similar. The additional parameters, cost, social values and economic effects, were added to represent a more holistic model that begins to represent an integrated framework. Without these parameters the current models inadequately address the concept of integration. By considering the similarities noted, including these and other additional parameters and merging the two approaches, an integrated approach is produced. Figure 4.3 presents a simplified, conceptual view of the proposed integrated approach within the context of a

radiological dispersal event (RDE). This representation provides the basic model of the integrated assessment approach for a RDE and is the precursor to the fully conceptualized model presented in Figure 4.4. The model in Figure 4.4 is the culmination of the integration of ERA and HHRA and is a linear representation of an iterative process.

4.2.3. Justification for integration

The USEPA's *Rules of Thumb for Superfund Remedy Selection* (USEPA, 1997b) promotes the inclusion of the ERA along with the HHRA. However, recent papers (Suter *et al.*, 2003 a and b; Toth & Hizsnyik, 1998; Rotmans & Dowlatabi, 1997) are still calling for this approach, thereby indicating that this inclusion is not being accomplished.

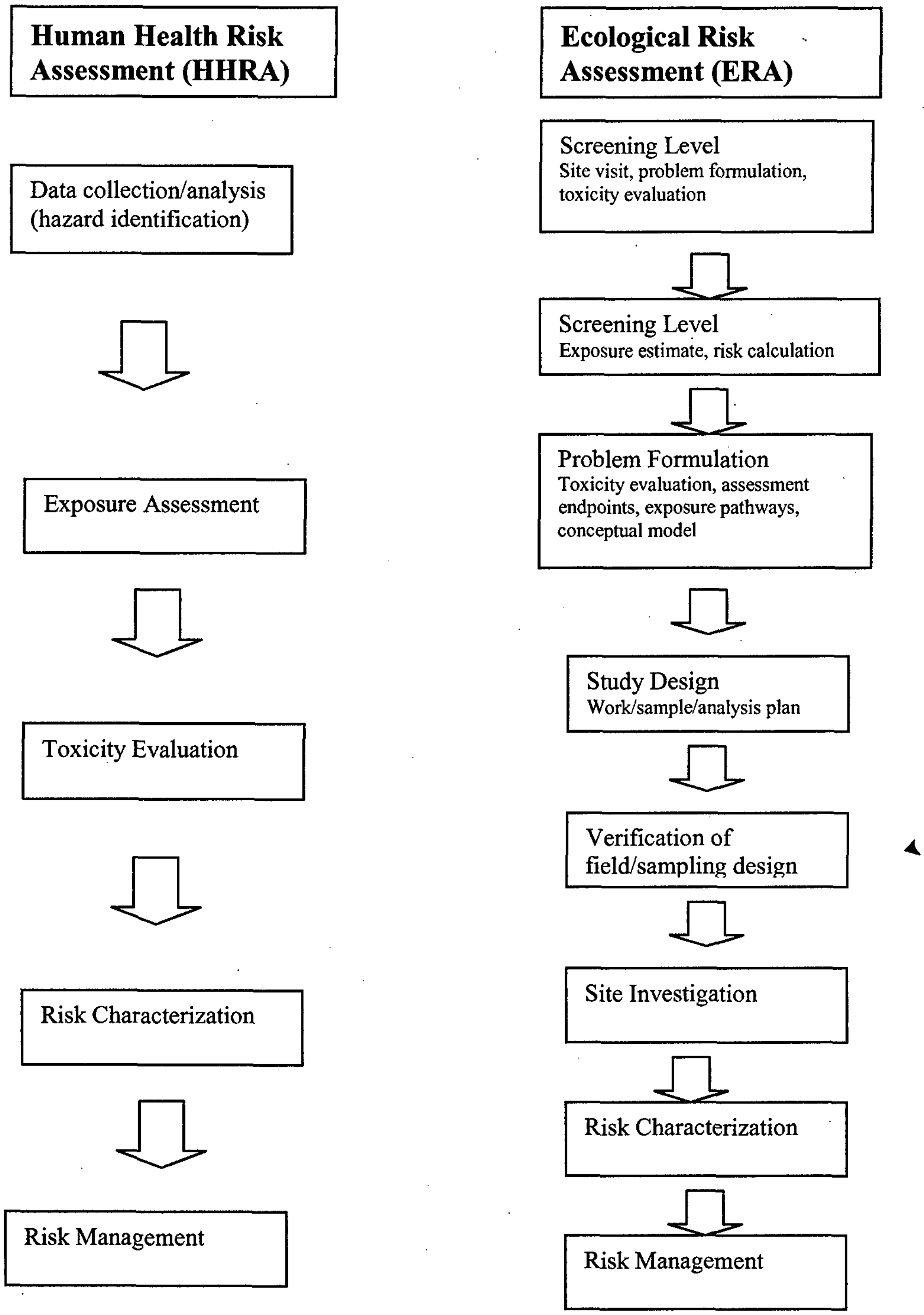

Figure 4.1. Current general approaches to human health and ecological risk assessment for Superfund (after USEPA, 1997a and 1989).

For the case of a RDE, both the HHRA and ERA should be done concurrently so as to save time and money, improve efficiency, enhance collaboration between all stakeholders and garner public acceptance. There are five advantages listed by Suter *et al.* (2003a) for integrating ERA and HHRA. Of the five, the three most applicable to a RDE are listed below.

1. Integration provides a more coherent and correlated view of the results. ERA and HHRA are represented differently using dissimilar endpoints and differing methods of risk comparison. These differences lead to difficulties in comparing one assessment to another in an attempt at reaching a common goal for remediation. The decision-makers are presented with assessments in different "languages" without common ground. Completing an integrated assessment with common language, endpoint structure and goals will simplify the decision-making process and lead to enhanced application of policy regarding a response following a RDE. It can also allow the greatest risk (weighted, perceived or actual) to be addressed (Suter *et al.*, 1995) thereby reducing or eliminating efforts toward receptors that are not at risk or have no significant regional value, as determined by affected scientific, political and public stakeholders.

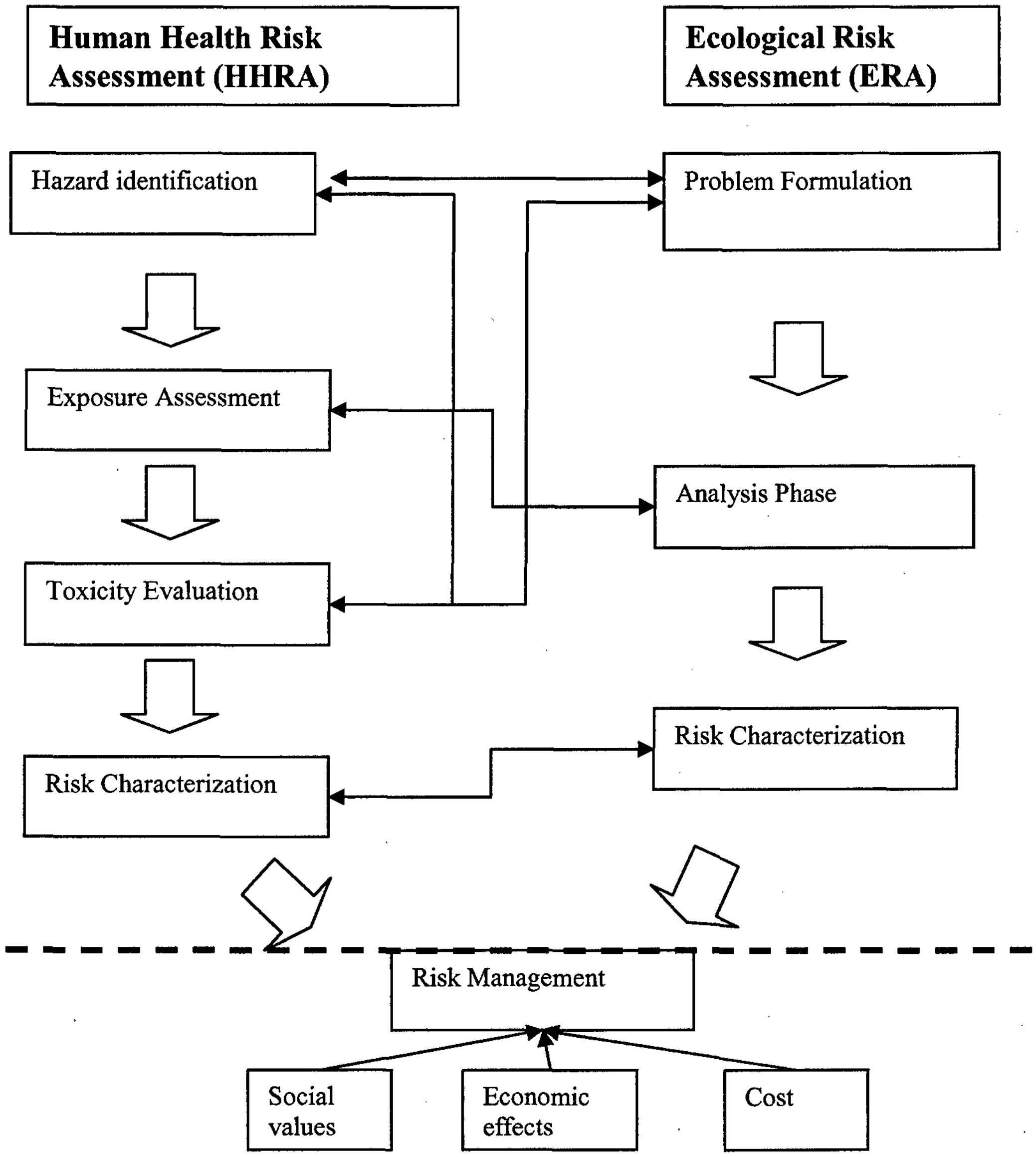

Figure 4.2. Simplified risk assessment approaches showing the areas of similarity (lines and arrows) between HHRA and ERA and the additional factors (below the dotted line) required for consideration in risk management (after USEPA, 1992, 1997a, 1998).

2. Ecological and human receptors are interconnected and interdependent and, therefore, should be considered as one system. Interdependence between the aquatic environment and the human environment are inseparable and so closely linked that the effect on one has a direct effect on the other (demonstrated through recreational uses, drinking water sources, and industrial uses, for example).

3. The efficiency of the assessment can be improved through integration. Energy deposition and decay of the radiological material is common to all receptors, that is, they are governed by the physical processes of interaction with matter. By evaluating the impact of the radiological contaminant on the entire system, duplication of these mechanisms can be avoided.

In addition to those listed above the following are also advantages of the integrated approach developed herein.

A1. More complete exposure pathways can be identified when considering ecological and human receptors as one system. The intricate relationships between trophic levels and possibilities of bioaccumulation can be considered.

A2. A significant portion of the evaluation is planned, and executed prior to the event. The pre-RDE phase preparation is critical to ensuring information is obtained and ready when the event occurs. During the problem formulation phase most considerations of the event can be considered. The hazard identification and toxicological assessments can

be evaluated prior to the RDE. This is possible due to the limited number of choices for the radioactive material as well as the known health and expected ecological effects. Obviously, real-time data collected after the event will be inserted into the model when collected and analyzed.

A3. Decision options can be considered *a priori* during the initial problem formulation phase, which is a key aspect of the entire process. A pre-assessment is conducted before the event occurs and provides a platform whereby plans, end-states and problems can be defined, deliberated and resolved to reduce the effect a terrorist is seeking. Advantages for this are numerous. First, it provides an opportunity for stakeholders to be identified and included in the planning before the actual event. If the event occurs, it is likely that some manner of chaos, mistrust and finger-pointing will follow. During the pre-event phase these factors are not at issue, and the forum can be less threatening. Second, a clear and effective risk communication plan can be developed. Once the event has occurred lack of a timely response can greatly reduce the effectiveness and acceptance of the message (NCRP, 1994). Third, all involved agencies can be identified and contacted, and lines of communication can be established. Fourth, the identification of crucial resources (academic, technical, political) can be considered. Emergency responders and their capabilities can be identified. Shortfalls can be identified and remedied.

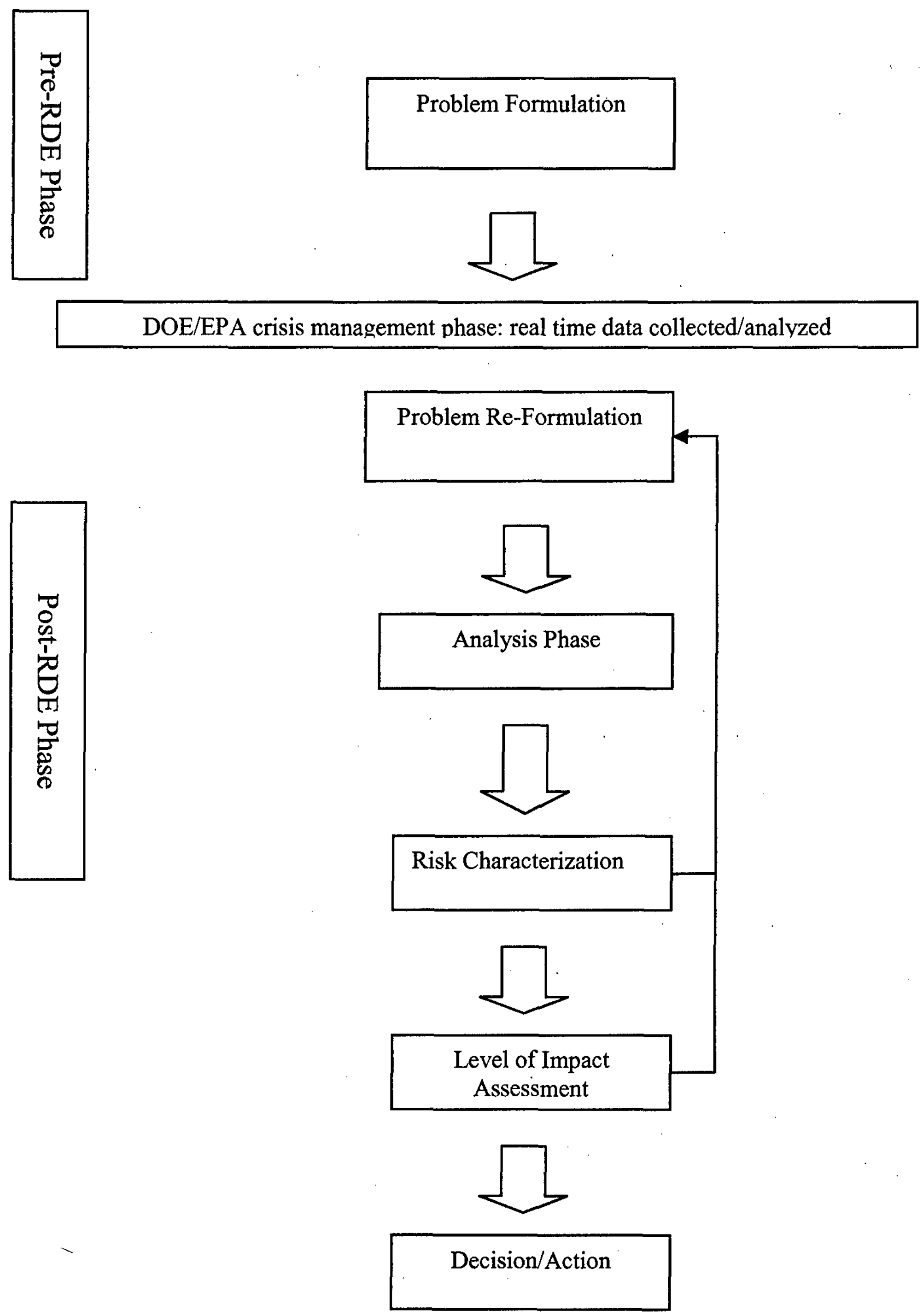

Figure 4.3. Simplified integrated assessment model within the context of a Radiological Dispersal Event (RDE).

This integrated risk assessment approach provides a framework for conducting the overall assessment of the impact of a RDE. The following section provides a description of the Level of Impact (LOI) Analysis.

4.2.4. Level of Impact (LOI) analysis

The Level of Impact (LOI) analysis (Figure 4.4) is a unique approach to assessing the impact from a RDE. The conceptual model integrates ecological and human health assessments into one holistic, *environmental* assessment which allows for the inclusion of many parameters not traditionally considered. It results in an assessment of the overall impact the release of radioactive material has, or might have, within a defined region. A region can be defined geographically, topographically (to account for surface water flow), hydrogeologically (to account for ground water flow), politically, or by any other means deemed appropriate by the stakeholders. Sub-regions are smaller areas within the defined regions. The delineation of the regions must be considered and defined in the problem formulation phase as the availability and allocation of resources might depend on the defined area. Variations in assessments across regions are acceptable, and results can be compared for determining priorities in resource allocation. The LOI analysis is conducted following the risk assessment proper and incorporates the scientific information and data available as well as various social and economic parameters. In addition, other factors can be added at the request and agreement of the stakeholders. The LOI analysis is an iterative process conducted for the evaluation of each region or sub-region of interest.

The approach is primarily qualitative in that it depends largely on the input, assessment and valuation of the parameters by the identified stakeholders and is determined regionally. The weighting factors are, likewise, determined at the regional and/or sub-regional level. This is an adaptive and flexible approach that can be shaped to fit each unique region or sub-region. The following is the general LOI equation.

$$LOI = \alpha E_i + \beta E_c + \gamma S + \delta H + \varepsilon C$$

Where:

E_i= economic parameter (impact on local/regional economy such as loss/decrease of revenue)

E_c= ecological impact

S = social impact

H = human health risk

C = cost of remedial action

α, β, γ, δ, and ε = sub-region specific weighting factors

Although the input parameters are primarily qualitatively assessed, the LOI analysis provides a quantitative result. It allows the qualitative aspects of the assessment to be converted to a quantitative method based on the input from both the pre- and post-event phases and on the decisions made by the stakeholders. This is an acceptable approach according to the USEPA (1998). Furthermore, this approach is similar to the current practice of the USEPA of developing site specific cleanup goals for hazardous waste sites, in that it allows for region-specific analyses based on region-specific information or considerations. The

relative value(s) of the LOI will provide a means whereby the impact(s) to the region can be compared and actions prioritized. The weighting of each parameter is left to each region, i.e. local stakeholders, as are the individual parameter values because these could differ from region to region.

Parameter values are based solely on the expected or potential *severity* of the impact that a parameter might present within the context of a RDE. The values range from 0-10. The weighting factors are based on the *probability* of the parameter impact and range in value from 0 to 1.0, but must sum to 1.0. The determination and valuation of the parameters and weighting factors could be difficult to ascertain because application to this scenario is unique and there are a limited number of cases involving uncontrolled releases of radioactive material. However, the events at Chernobyl in 1986 and Goiänia in 1987 provide a basis whereby these factors may be derived and are, at present, the closest "models" to a RDE. A summary of these events and their application to responding to radiological terrorism can be found in the literature (Steinhausler, 2005; Steinhausler & Wieland, 1998). The weighting factor can be used as a prioritization tool for assessing the impact a given parameter might have on a region. The weighting factor could be based on the perceived impact a given parameter might have on the region.

None of the parameters should be considered in a vacuum or considered as an independent variable due to the interconnectedness of the parameters. As will be shown below each parameter can have an effect on another, and so the relationship between each pair, i.e. parameter and weighting factor, as well as any

other parameter deemed appropriate and added to the equation during the problem formulation phase, is significant and must be assessed carefully.

The economic parameter, E_i, is a value based on the economic disruption the RDE might have on the regional or sub-regional economy. It is a compilation of agricultural impact (decrease in crop production due to the presence of contamination and the subsequent limitation on land use or decrease in sales due to the perception of contamination), decrease in industrial output, impact on education (decreased enrollment within the affected area) and effects on tourism and recreation (decreased visitation and recreational opportunities within the region). The economic impact could be caused by the actual presence of the contaminant or by the perception of its presence.

The ecological parameter, E_c, represents the actual expected or present degradation of, or impact on, a defined ecological receptor. The level of degradation must be clearly identified as an assessment endpoint in the problem formulation phase. For example, when a specific species is identified as the indicator species, the effect might be noted as a decrease in fecundity by a defined percentage. Perception of the risk to ecological receptors should be neglected so that the actual risk is the only consideration. This parameter could also include a consideration of ecological services and the impact this would have should these services be lost. An example would be the service provided through a sole source aquifer. The aquifer provides a clean, renewable drinking water source. Contamination of the aquifer could render it unusable.

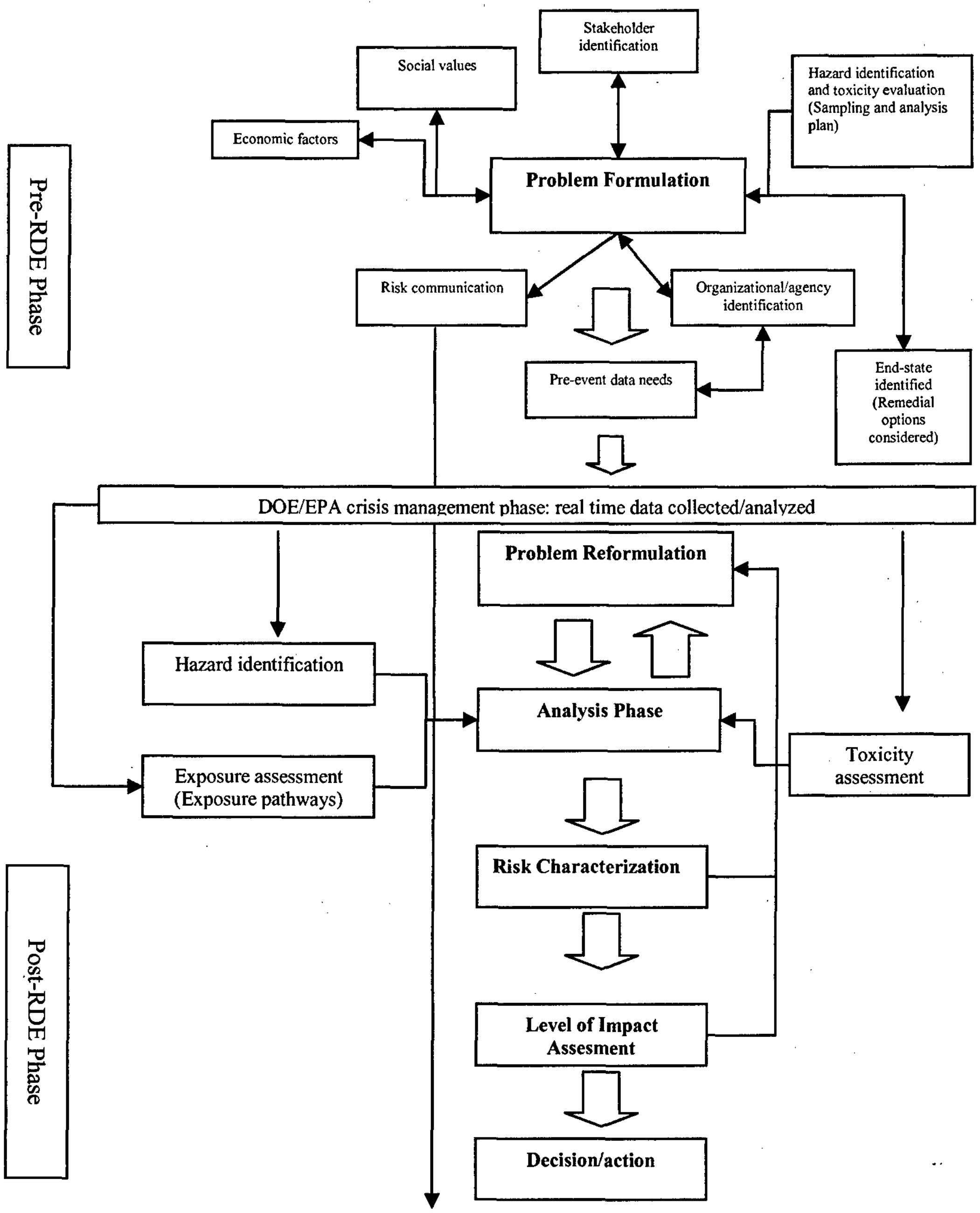

Figure 4.4. Level of Impact (LOI) analysis conceptual model incorporating an integrated assessment.

The social impact parameter, S, represents the value the regional stakeholders place on the presence of the contamination from a perception perspective. This value is based on how the stakeholders view the presence of the contaminant and how they perceive its presence as a whole on the sub-region. The assessment of this impact could be affected by any or all of the other parameters because they will affect the perceived effect on the area. This factor could also be a consideration of the loss of an historical facility due to the presence of contamination and subsequent remediation that could destroy or degrade the value of the item. There also could be many other considerations that can be included as part of this parameter, and they should be defined in the problem formulation phase. This factor should be considered during the problem-formulation phase so as to identify key facilities or sites, as examples, that might be impacted.

The human health risk parameter, H, is the value the stakeholders place on the actual risk to human health as a result of insult from the radioactive material. Based on the hazard and toxicity assessments this value could range from negligible to high. The perception of the risk should be excluded from this value and be based only on the actual representation of risk.

The cost of remediation, C, is *considered* during the problem formulation phase but is only an estimate because it is based on an assessment before the event occurs. This parameter is likely to vary significantly and will be adjusted once the event occurs. It can not be closely estimated until a complete assessment is conducted and the extent of the contamination is known. Cognizance of the contaminating agent will allow for some level of estimation. Typical types of

remediation techniques for radioactively contaminated sites are containment followed by removal and subsequent burial. Burial costs can be easily estimated but are based on total volume that will be unknown until the extent of contamination is known. In the case of aquifer contamination, containment may not be a feasible alternative, but this is based on the hydrogeology of the aquifer. Confined aquifers provide a natural containment, while unconfined aquifers could be difficult to model due to their complex transport and surface and ground water interactions. Ground water sequestration of the contaminant is both technically difficult and expensive.

Physical degradation, destruction or disruption in the region is a consideration of the impact the remediation can have on regional ecosystems, agriculture, industry, recreational uses and residential areas, to name a few. This can be integrated with any of the parameters above and should be considered as a factor in determining the overall impact. Should the physical disruption be so severe so as to cause the "destruction" of an area from an economic perspective, the stakeholders may want to weight this factor heavily.

The LOI analysis results in a value whereby an overall assessment can be determined by comparing the computed value from the LOI equation to the parameter range in the Impact Analysis Table (Table 4.1). The LOI value is subjective, but adaptive and flexible, and the latter are critical when applying the model to an intractable problem such as a RDE. Stakeholders within each region or sub-region will determine the relative parameter values. The value of the approach is that it allows a quick, simple regional comparison upon which

decisions can be made regarding actions to take. The weighting factors will enable the evaluator(s) to prioritize actions based on the relative weights assigned by the stakeholders. The proposed range of values is fixed. Examples of impacts, presented in Table 4.1, can be adjusted as needed to determine the relative impact but should be fixed regionally so that prioritization and resource allocation can be equitably assessed.

The process of analysis can be likened, illustratively, to a series of concentric circles around the area of impact (Figure 4.5) and assessed using the Impact Analysis Table (Table 4.1). The innermost area is the area of release, or epicenter, and is surrounded by larger areas of initial concern. This area is likely to be the area with the most severe impact and, thus, requiring the most remedial action. The entire area is not likely to be affected, i.e., homogeneous and complete dispersion is not probable. The outermost boundary is the demarcation beyond which negligible impact is projected. The evaluation of the impact begins at the innermost boundary so that resources can be utilized most efficiently and at the points of highest impact or concern. (This is counterintuitive to those involved in emergency response involving radioactive materials as the course of action is typically initiated at the outermost boundary to ensure the safety of the responders. The LOI, however, is designed to assist decision-makers in the recovery phase for the most efficient allocation of resources based on prioritized levels of impact.) It must be recognized that due to the complex surface and ground water interactions, topographical variations and geological substrate within the released area that the areas of impact will not be ideally delineated as

in Figure 4.5. The actual dispersion of the released material will be dependent on many factors and will be in three dimensions.

Once an assessment has been conducted for this smaller area, the analysis is conducted at increasingly larger areas, i.e. iteratively as demonstrated in Figure 4.4, until the analysis reveals the boundary beyond which no significant impact exists (value range of 1-3, for example, in Table 4.1).

Parameter Range	Impact
1-3	Minimal impact to environment, negligible costs resulting from economic disruption or remedial costs. No loss of services.
4-7	Loss of services 1 day to 1 week. Potential adverse impact on environment. Drinking water restrictions considered for short-term.
8-10	Significant environmental impact. May require relocation of population, expenditure greater than $1M in economic disruption or remedial costs expected. Loss of services exceeds 1 week. Alternate source of drinking water required.

Table 4.1. Example of an Impact Analysis Table.

Regional evaluations can be conducted concurrently in order to reveal similarly affected areas in close proximity. The assessment value of each area can then be used for comparison to the other areas for prioritization of resource expenditures.

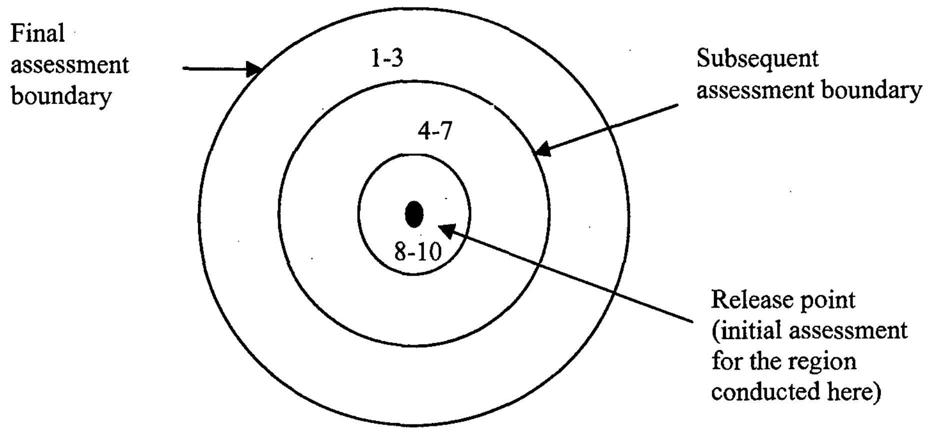

Figure 4.5. Illustration representing the Level of Impact Analysis. The outermost circle is the area beyond which negligible impact is expected. The point in the middle represents the area of most significant impact and, therefore, the focus of recovery/remedial action. Values within the boundaries correspond to the Impact Analysis table parameter values.

Figure 4.6 presents an example of how the impact assessment might appear on a regional scale, i.e. within the Mad River Watershed (discussed in Chapter 6). Illustratively there are three regions within the watershed that have been affected to some degree by a RDE. That is, radioactive material has been detected. The three bounded areas would be assessed using the LOI with integrated assessment beginning at the innermost point as previously described.

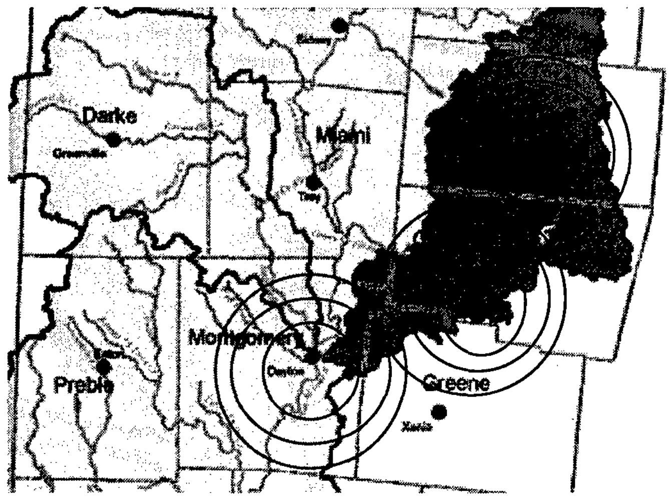

Figure 4.6. Conceptual view of the Level of Impact Analysis on a regional basis. Three regions affected by a RDE are represented here and show how the impact assessment may overlap.

Based on the results of the assessment priorities would be set regarding recovery actions. During the problem formulation phase all pertinent ecological and human health data would have been accumulated and pre-analyzed (discussion to follow). There may be areas of overlap. For this reason, the impact analysis values and descriptors must be consistent. The highlighted area in red indicates the boundary of the Mad River Watershed.

The following is a discussion of each of the steps in the LOI analysis with the integrated risk assessment approach. It is acknowledged that it is impractical to do this analysis for every region and/or sub-region identified. Therefore, vulnerability assessments, not explicitly addressed in this study, of various

regions are imperative to identify the most attractive target areas from a terrorist's perspective (see below for an explanation of priority areas). These assessments are mandated for critical infrastructures, of which water systems are one, by HSPD-7, and could, conceivably, be extended to include areas that affect the critical infrastructures.

4.2.5. Problem formulation

The problem-formulation phase is comparable to the scoping phase done within a typical risk assessment. However, within the context of a RDE, and in stark contrast to a typical risk assessment, it is conducted *prior* to the event and is, by design, comprehensive because planning before an event is less chaotic, and likely less expensive, than planning and implementation after an event. Much of the information can be pre-evaluated based on the limited number of radioactive materials suitable for release as a radiological weapon and accessible to terrorists. The effectiveness of conducting the evaluation at this point hinges on the identification of targets of interest to terrorists. Socially, economically and/or politically attractive targets or those highly vulnerable must be identified and prioritized for this analysis to be practical. Conducting the analysis from this perspective is keeping in line with the expectation that this approach will result in a more effective and efficient response and minimize the impact of a terrorist act involving radiological materials.

There are several factors contributing to the effective formulation of the problem, and these are identified in Figure 4.4. Although the model suggested is

comprehensive it is conceivable that other factors will be identified by the stakeholders. Identification of the stakeholders, thus, becomes a critical step and must be accomplished prior to all other steps. As previously noted, it is expected that the USEPA will be the lead agency for recovery and mitigation. It is, therefore, incumbent on them (specifically, the Office of Solid Waste and Emergency Response) to initiate the identification of the stakeholders within given regions. Once a core group has been selected, the group will take the lead for further identification of stakeholders. It is imperative that the initial, core group be comprised of a cross-sectional representation of the region so as to ensure that all points of view are expressed. Such representation will aid in reducing government and independent agencies or organizations from exercising undue influence without full consideration of all stakeholders' views and result in decentralized management.

Stakeholder views will drive the identification and pre-assessment of the social and economic factors, and their continuous involvement is integral to the success or failure of the approach. The regional stakeholders are most likely to be familiar with and cognizant of the interactions and interconnectedness of these aspects. They will assist in developing a list of potentially impacted businesses, industries, recreational facilities, agricultural areas, historical landmarks and other areas of potential concern to the residents of the region. These individuals represent the population. Their decisions will guide the outcome of any required remediation or mitigation actions. The stakeholders should determine the desired end-state of a contaminated region and assess the merits of the various remedial

options available and current and future projected land uses. The potential land uses are a critical information parameter in determining final remediation goals. This group also will be valuable in determining the most effective risk communication methods and will include the persons best suited for delivery of information (see Section 4.4.2 below). Once the stakeholders are identified it is imperative they meet to begin discussion regarding the economic and social factors as well as the desired end-state.

The scientific community is a critical group in the stakeholder population. They will assist in determining the pre- and post-event data needs to ensure that once the event has occurred information can be quickly gathered, evaluated and released. This information will be critical to the development of the risk communication plan.

Identification of the end-state is essential to the successful implementation of the LOI approach because it will determine, to a large part, the data requirements, risk communication issues and level of assessment needed in determining ecological and human health hazards as well as costs associated with any actions needed to achieve the end-state. All stakeholders should have an equal role in deliberating the potential remedial options and in considering ramifications of each option. Not all possibilities may be achievable, technically or financially, so a method to resolve disagreements must be developed during this stage as well. Determination of the end-state is likely to be based on contaminant concentrations, associated radiation dose levels, and land use projections. However, since there are no nationally or internationally established levels

(Steinhausler, 2005, Conklin, 2005), this is likely to be a significant point of contention and must, therefore, be discussed and resolved at this point. The National Research Council (2005) has reiterated its position on the linear-no-threshold model for dose response. Likewise, the USEPA follows this approach in determining their cleanup levels (USEPA, 1989). Due to the importance of this issue and its associated controversy (Elcock *et al.*, 2004), this must be discussed and resolved as early as possible. Conklin (2005) has proposed protective action guides for various phases of the response and recovery that are based on the substantial data available from previous radiological and nuclear event planning. Another aspect of the end-state discussion is the storage and disposal of any contaminated media that may be generated. The cost of on-site or off-site storage or permanent disposal may be prohibitive if large waste volumes are generated.

The Department of Homeland Security will have immediate operational control of the region along with the Department of Justice until such time as the area is released to the USEPA. It is at this point of departure that federal, state and local organizations and agencies must coordinate an appropriate response. Failure to clearly identify these organizations and a working chain of command well before the terrorist event will lead to delays and/or failure of the plan. Through the early creation of the stakeholder group, organizations and agencies available within the region can be identified and their roles defined or refined. The role and function of each agency and organization must be unambiguously acknowledged. Associated resources (people, monitoring equipment, vehicles,

medical facilities, law enforcement, communication media and laboratory facilities) should be identified, evaluated and inventoried.

A pre-assessment of the associated hazards and toxicity can be conducted due to the limited types and quantities of radioactive material available and considered attractive for a terrorist's purposes. The hazard evaluation should be conducted using worst reasonable case assumptions and adjusted after the event occurs. Identification and inventory of ecological receptors known to be susceptible to or at risk from acute radiation doses should be noted within given areas of priority. (Areas of priority are those considered likely or potential targets for a terrorist attack. The process whereby an area is designated as such is not in the scope of this study. Generally, evaluations such as these are conducted by intelligence-gathering agencies. Areas of priority can be identified during problem formulation so that efforts can be concentrated on those areas. An example of a high priority area might be a recharge area for a sole source aquifer.) To expedite the assessment the sampling and analysis plan must be developed to allow for quick adaptations once the event has occurred. Relative assessments can be made to assist in the consideration of remedial actions (not specifically addressed in this study) and the desired end-state. Identification of models and assessment tools is discussed here. Preliminary dose estimations, plume modeling and transport will provide hazard and toxicity assessments that can be used for planning purposes. This step will add relevance to the overall evaluation (Toth and Hizsnyik, 1998).

The risk communication plan can be initially developed once the above steps have been completed or are well underway. This is the one aspect of the approach that must be developed to bridge the pre- and post-event response but must also address the crisis-management phase, which is not specifically addressed in this study. However, for purposes of continuity, the risk communication plan must cover all phases of the response. The communication plan should include early warning notifications, pre-written media releases, the method of release and established release times. Education of the stakeholders can be part of the risk communication plan and should begin well before any anticipated terrorist event. Failures in this phase or an incomplete communication plan will lead to delays in the problem-reformulation phase (see Section 4.4.2 for further detail).

The length of time spent on the pre-event aspects will be directly proportional to the expected complexity of the RDE. The time invested will directly support the actions and decisions made after the RDE and, therefore, lead to a more efficient and productive assessment after an event.

4.2.6. Crisis-management

Crisis management is conducted by the responding agencies previously noted (initially the DHS and DOJ and subsequently the USEPA). This phase is beyond the purview of this study but the information collected will be critical to the next step. Real-time data will replace the pre-event estimates to refine the results. Data and information gathered here will directly influence the hazard, toxicity and exposure assessments.

4.2.7. Problem reformulation

The problem is reevaluated during the reformulation phase and is conducted to refine the estimates made during the pre-event phase. Each of the aspects reviewed and assessed in the pre-event phase will be reviewed again with current information. It is imperative that communication between the responding agencies is open and clear. Adjustments to the pre-assessment problem formulation will be conducted. Delays in communication will hinder the effectiveness of the response. Since the problem-reformulation and analysis phases are conducted iteratively, adjustments will be continuous throughout the phase. This step should be quick and efficient because the majority of the analysis was conducted in the pre-RDE phase.

4.2.8. Analysis

The analysis phase consists of evaluating the collected and analyzed data from the responding agencies. Post-RDE adjustments to the sampling and analysis plan will be made on the basis of real-time variations and circumstances not known prior to the RDE but should be minor in nature. Once data has been obtained and analyzed by the responding agencies adjustments to dose estimations, plume dispersion and transport models can be made. These will be essential to the overall risk characterization. Analyses should follow common practices for the types and quantities of samples collected. The sampling and analysis plan outlined during initial problem formulation should clearly identify all requirements pertinent to this step. Arrangements for sample collection, transport

and analysis should be prearranged to prevent delays which may negatively affect the risk characterization step.

The toxicity assessment and hazard identification should be able to be conducted relatively quickly because they were pre-evaluated during the initial problem formulation phase. At this stage of analysis the real-time data will have provided enough information to qualify the type of radiation released. This information is critical to conducting a full toxicity and hazard assessment for human and ecological receptors within the affected area.

All possible exposure pathways for both human and ecological receptors will require some time to delineate because these will be largely dependent on the release point and could not have been completely defined during the pre-assessment phase.

4.2.9. Risk characterization

Risk characterization will be conducted using traditional approaches. Since the released agent in the case of an RDE is radioactive, carcinogenic risk factors (slope factors published by the USEPA) should be used for human health evaluation. The National Council on Radiation Protection and Measurements (NCRP) Report No. 123 should be consulted for consideration of acceptable dose limits for aquatic organisms. Dose limits proposed by Jones *et al.* (2003) provide an overall ecological approach for dose considerations to both aquatic and terrestrial biota. The determined ecological and human health values will be

inserted into the LOI equation. This will lead to a resulting value that provides an overall *environmental* characterization of the risk.

4.2.10. Level of Impact Assessment

The LOI assessment is the final, culminating step prior to decision-making and subsequent action or inaction. This step provides the means whereby an overall assessment of the region can be compared to other regions or sub-regions for estimating the impact. Table 4.1 provides a useful, but adaptable, gauge to assist the decision-makers in prioritizing actions. The resulting value is likely to vary with updated data such as plume transport and meteorological changes. This will lead to an iterative process where new information is fed back into the loop at the problem-reformulation step and a modified LOI value could result. Once all data inputs are completed the iteration stops and a decision regarding action(s) to take can be made.

4.2.11. Decision/Action

This step is analogous to risk management. Any decisions or actions will be based on the integrated assessment. They are dependent on the LOI assessment and are within the conditions agreed upon during problem formulation or reformulation. A resultant decision could be that no action is required. Should this decision be implemented the risk communication must be carefully designed to ensure that as complete an understanding as possible of all the parameters is

presented. Uncertainties must be addressed to ensure the stakeholders are aware of the limitations and implications of such a decision.

Figure 4.7 presents one of many possible conceptual expectations of an impact with respect to the elapsed time after a RDE without an effective approach in place prior to the event. The "w/o plan" curve suggests that the impact of the RDE is more significant, financially and temporally, immediately following the event because significant resources are expended in developing a plan of action and conducting the risk assessment. Mitigation and recovery actions cannot be immediately implemented and, therefore, increase the significance of the impact. The representation could be presented through many different curves based on any single parameter or combination of parameters previously introduced, but is presented as one simplified figure for illustrative purposes only.

Without a developed and implemented plan, the impact, expressed via financial and temporal costs, is expected to spike in the short-term crisis-management phase when efforts will be conducted in the midst of chaos. In most instances where no plan has been developed or implemented, costs are difficult to control and, due to the immediacy of the need, more expensive (Kelly, 1995). Additionally, relying on emergency appropriations after an event, i.e. "no-cost-limit", rather than planning for an event and having a specified fund can contribute to dysfunctional strategies leading to an inefficient response and recovery (Kelly, 1995). As time progresses, a plan will be developed, in the short-term consequence-management phase and will be fully implemented in the mid- to long-term phases. In these latter phases there will be a "ramping up"

period where implementation details are sorted out, roles and responsibilities are defined and on-site evaluations are conducted. Once the plan is fully implemented the impact will level off, i.e. during the long-term consequence-management phase. During the later consequence-management phase costs could drop significantly to parallel those of the in-place curve discussed next. In comparison to the curve with a plan at the time of the event (H_0), the impact without a plan in place will have been realized and will be more significant, relative to the curve with a plan. In comparison, the impact curve reflecting the in-place plan will have a pre-event expense of time and money as the plan is developed. At the occurrence of the event (H_0), there might be a gradual increase in impact that will quickly decrease to a lesser level in the short-term consequence-management phase. This decrease will come about as a result of the pre-assessment problem-formulation phase and the subsequent capability and flexibility of the LOI approach to be refined once current data is available. The general shape of the two curves presented, post-H_0, are similar. Both expressions never reach zero, owing to the likelihood of long-term monitoring requirements. As stated above, the expressed magnitude of difference is conceptual and can be substantially more or less than shown. The actual difference between the two curves cannot be realized until after the event has occurred and real costs have been tallied. If the area under the curve representing the LOI approach is less than that of the curve without a plan, then the effectiveness is demonstrated. To validate this expectation specific data must be collected from the onset of the planning through realization of the end-state. Man-hours, operational

expenditures (e.g. labor, equipment, laboratory analysis) and remediation costs (actual dollars spent and ecological impact through potential loss of natural resources or environmental services) must all be tallied to show the total impact.

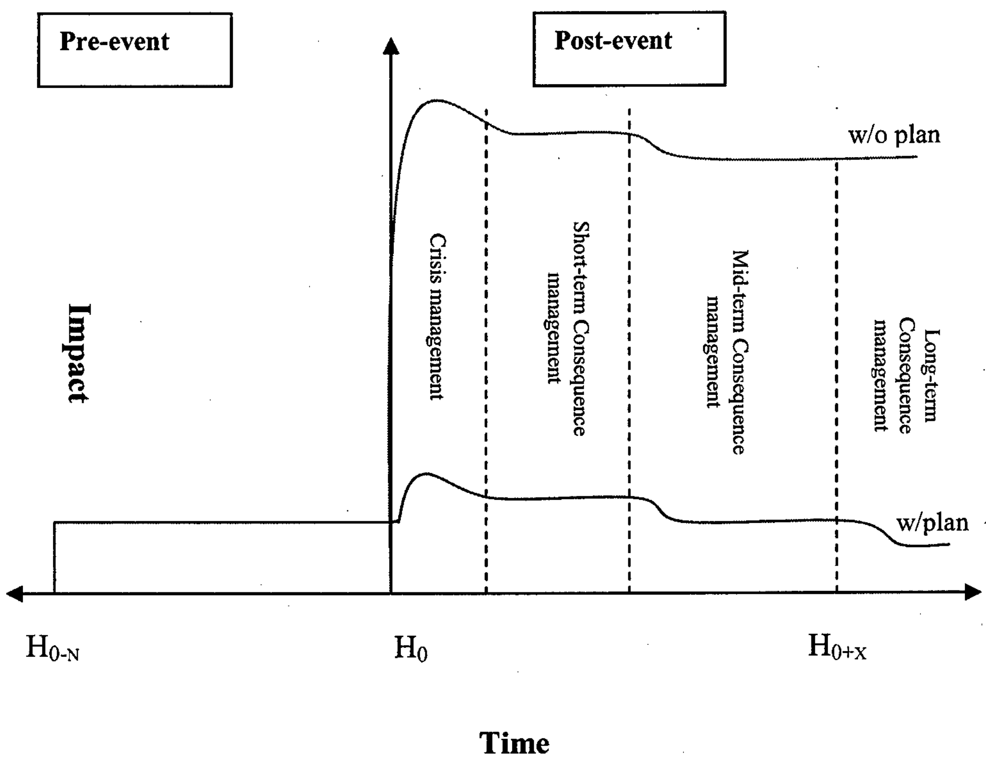

Figure 4.7. Conceptual expectation of the Time v. Impact using the proposed integrated LOI methodology. Impact is defined as temporal and financial cost.

4.3. Data and Information Requirements

Evaluation of an area following a RDE would be impossible without the collection and analysis of appropriate data. In an endeavor such as the evaluation of an area potentially contaminated with radiological materials, the data must be appropriate, adequate (quantitatively and qualitatively), verifiable and current. In order for this information to be useful background data for the area must be collected well before the event and over some defined time period. This will provide the basis for comparison to real-time data after a suspected release and provide the basis for determining the extent of the release and evaluating the impact. To this end, the following sections detail the types of data and information required in the event of a RDE in an ambient waters source. (Although the scope of this study is primarily focused on the consequence-management phase, after this has ended there are some aspects of data collection and information management that must be addressed and for the purpose of continuity, span both the pre-event phase and post-event actions. Without the inclusion of this information, the analysis the impact of the RDE could not be fully conducted.)

4.3.1. Pre-RDE

Radiological background concentrations vary widely throughout the U.S., and knowledge of this along with the background data specific to the area of concern will allow decision-makers to make critical decisions. The natural variation in radiological background will also provide the risk communicators

with a method of comparison. The USEPA has noted the importance of background. They note that knowledge of background data, and its associated risks, may allow community members to place risks in perspective (USEPA, 2002).

The historical data of the area must be evaluated so that the areas that have higher background concentrations can be identified. The existence of past radiological disposal sites, areas with higher natural uranium concentrations, previous manufacturing and military or government sites must all be identified and ambient readings obtained. This information will be the basis for decisions made post-RDE. By comparing post-RDE data to ambient or background data determinations regarding personnel safety and potential environmental damage will be made. For the case of an ambient water source release, data such as hydrogeological information (water flow patterns, water withdrawal and recharge rates, topographical data, locations of recharge, locations of discharge, reservoirs, dam locations), recreational access points, well sampling points, drinking water withdrawal points (publicly and privately owned), human accessible river points, riparian zones, and the presence of any indicator species of flora or fauna (species, quantity, locations) must all be gathered and assessed. It is also important to note all surface and ground water interface areas. Aquifer specific data must be collected to evaluate any potential impact on drinking water supplies. Water use rates and purposes for residential, recreational and industrial nodes must be identified.

Predetermination of sampling locations, quantities of samples, and methods of collection are needed and should be identified in the problem-formulation phase. Upon suspicion of a release this information can be adjusted to accommodate real-time information. A preplanned data reconnaissance route should be determined for areas deemed of highest importance. This route should be flexible to allow adaptation for real-time data. Determination of who will collect, prepare and analyze the samples should be made during the problem-formulation phase. Inventory of all available detection, analysis and sampling equipment should be conducted during problem formulation, as well. A quality control system to periodically verify and check all systems and equipment along with calibration must be developed and maintained. Training may be required for various groups of individuals to ensure redundancy in user capability.

Identification and location of response resources is critical so that their response can be efficiently directed. Those resources within closest proximity to the RDE can be deployed for appropriate and timely response. An evaluation of the capabilities of the responders to include detection and sampling equipment, personal protection equipment (such as coveralls, gloves, and respirators, if needed) is essential. Additionally, medical facility locations must be noted. It is well documented from the event in Goiänia, Brazil, that although only a few individuals were actually contaminated or presented with valid symptoms of acute radiation exposure (Rosenthal *et al.*, 1991), nearly 112,000 individuals presented due to concerns of exposure and psychological impairment (Steinhausler & Wieland, 1998).

Notification rosters for local, state and federal responders should be developed during the problem formulation phase. A clearly articulated and published chain of command for response, with redundancy, is essential to providing a timely and effective response. For example, each organization must have multiple notification points and modes of notification. If the first person on the list can't be reached via land line, then they are contacted via cell phone. Should this fail another individual at that same organization (hopefully of equal grade/rank so decisions can be made effectively) is contacted via land line then cell phone and so on until the notification chain has been exhausted (this includes media and local, state, and federal stakeholders).

4.3.2. Post-RDE

The post-RDE recovery will occur after the initial response team(s) have conducted and concluded their respective actions. The Department of Energy, in accordance with the National Response Plan (DHS, 2004), will have response authority over all radiological terrorism events during the crisis-management phase of the response. They will provide initial reconnaissance and recovery, data collection and analysis. Once they have completed their actions the response will transition to the USEPA for recovery and remediation during the consequence-management phase of the response. The data collected during the crisis-management phase will determine and direct, to a large extent, further data and information collection requirements.

Specific data and information needed in this phase are listed below. Many of the same data sources are needed in pre- and post-event phases. The required data and information below are considered real-time and will be inserted into the LOI analysis loop at the appropriate step.

1. Meteorological conditions. These are needed as they may affect the distribution and movement of the radiological material once released. If the material is released in a large reservoir, ambient air and aquatic temperatures will affect mixing within the water body.

2. Topographical and hydrogeological information. This will provide the responders with information to predict plume dispersion based on flow, areas of potential stagnancy and surface and groundwater interchanges.

3. Population demographics. These are needed to ascertain the potential for health effects and the appropriateness of relocating human populations.

4. Ecological receptors that might be indicator species. Observation of these species can assist in predicting effects to local ecosystems which, in turn, will help determine the level of impact on other ecosystems.

5. Type(s), quantities and chemical nature of the radioactive material released. The chemical nature of the released material will provide information necessary to predict fate and transport within water and adjacent soils. This information will be useful in evaluating remediation options. The type and quantity are critical to evaluating potential ill effects to both ecological and human receptors. Because dose is directly related to both of these factors, both type and quantity are critical. Inherent in this

analysis is the identification of target organs for the specific radionuclide released. Each radionuclide and type of radiation, affects biological (physiological) systems to varying degrees based on their respective radiobiological sensitivities of the physiological system.

6. Exposure pathway(s) for all receptors. Assessing the risk to a receptor cannot be conducted without a complete and accurate exposure pathway. General pathways can be pre-identified for areas of highest priority, i.e. those areas identified as potentially attractive targets, in the problem-formulation phase, as previously discussed, and modified once the RDE has occurred.

7. Current and future land use. Post-event response and recovery may affect the land use potential identified prior to the event. Land use will, to a large extent, help determine the level and type of remediation alternatives considered and finally undertaken.

4.4. Risk Communication

4.4.1. Introduction

The effective and appropriate communication of risks is critical to belaying the fears, uneasiness and potential chaos surrounding a terrorist event involving radiological materials (Becker, 2005). One of a terrorist's goals is to create an environment of fear and panic leading to mistrust of the government and subsequently to the deterioration of social order. To combat this, the decision-makers and stakeholders must develop a pre- and post-RDE plan for risk

communication. A plan cannot be developed after the event has occurred because it is too late and will be ineffective (NCRP, 1994).

The capacity of the audience to absorb and process the information is a key element in the success of a risk communication plan (NCRP, 1994). Establishing this capacity begins long before the event occurs and is a result of the level of education a person receives prior to an event. Education comes in many forms and can be formally provided, e.g. through academic institutions, public service announcements, news media or personal encounters (NCRP, 1994). Regardless of the source (assuming it is credible), the amount and accuracy of the information is paramount to ensuring a person understands the information provided prior to and after a RDE. The NCRP (2001) has noted that policies and plans addressing both short- and long-term communication issues must be developed. The plan should involve open interaction between decision-makers and the receiving audience in order to enhance the reception of the message and gain acceptance of the desired action.

There are several noteworthy publications about aspects that influence effective risk communication. The following is a summary of the points germane to a RDE.

1. The perceptions of the audience will affect the reception of the message (NCRP, 1994).

2. The perception of risk associated with radiation is complex (Sandman, 1986).

3. Risk from radiation accidents is perceived to be beyond one's control (NCRP, 1994, Slovic, 1990).

4. Communication is interactive (Wolfe, 1993; NRC, 1989).

5. Political, economic and historical elements contribute to acceptance of the message (Wolfe, 1993).

6. Communication is successful only as far as the audience's level of understanding has been enhanced within the limits of available knowledge (NRC, 1989).

7. There is not just one type of delivery medium that is most effective. An effective risk communication plan should and will involve many media and formats (NCRP, 1994; NRC, 1989).

8. Successful communication does not always lead to a better decision because the communication is only one part of the decision-making process (NRC, 1989).

9. Risk communication is a fixed cost that can prevent larger damage (Fischhoff, 1995).

10. A successful plan achieves trust and credibility (NCRP, 2001).

The final plan will require tailoring to fit the circumstances of the region for which the pre-assessment is conducted and is dependent on prioritization and assessment of likely targets. Without designating a specific region only generalities are appropriate at this point. The recommendations that follow regarding content of the message are intended to be useful for any type of a radiological release in any medium.

4.4.2. Pre-RDE

The pre-RDE communication plan must focus on educating and familiarizing the audience with the subjects of radiation and terrorism. One without the other will not suffice because these two topics are inextricably linked in a RDE. The pre-RDE message is at least as important as the post-RDE message. A multi-year study sponsored by the Centers for Disease Control and Prevention (CDC) (Becker, 2004) is underway to identify the needs of individuals affected by a terrorist act involving chemical, biological or nuclear/radiological weapons or material. The intent of the CDC research is to develop a "Pre-Event Message" to be used in conjunction with an anticipated terrorist event. Four universities (University of Alabama at Birmingham, University of Oklahoma, Saint Louis University, and University of California at Los Angeles) are investigating the information requirements and concerns of the public during a terrorist act involving a chemical, biological or nuclear/radiological agent and to more fully understand the role risk communication will play. In addition, these universities are studying the many factors involved in the development of an effective message (Becker, 2004).

It is recognized that the development of this information before the event is critical to its success. However, the release of this information, according to the study parameters, will not occur until the event has occurred -- a significant departure from the proposed approach herein. This multi-university project appears to be a step in the right direction, but release of the information before the event is an important step to preparing and educating the public. Informational

materials must be developed solely for the purpose of educating and not be alarming. Expansion of the CDC study to develop communication materials meeting these criteria should be considered.

It is essential that education of the stakeholders, at all levels, be provided as early as possible. People draw upon their education and experiences in times of distress, and these provide an important source of background information (NCRP, 1994). It is, therefore, critical that stakeholders be educated regarding the basics of radiation and terrorism prior to a RDE. Education, at many levels and in various forms can reduce the anxiety and impact of such an event (NCRP, 1994). The following are suggestions for the types of information stakeholders should be educated about with regard to a RDE.

1. The types of radiation.
2. Relative hazards from each type.
3. Sources of ionizing radiation.
4. Intent of a terrorist.
5. Basic protection steps for ionizing radiation (time, distance, shielding).
6. Who (and how) to contact for additional information.
7. How a person might be exposed.
8. Terminology unique to radiation and terrorism.
9. Background levels of radiation throughout the U.S. for comparison to release levels after a RDE.

As noted earlier the modes of delivery of a message are numerous. In the pre-event, non-emergency phase the possible delivery platforms are unlimited.

Newspaper, public service announcements (radio and television), internet, informative mailings, public meetings and formal training through university extension offices are all possibilities. Two of the most desirable platforms are television and radio (Becker, 2004). The primary intent of the message during this phase is education preparatory to the information released after the event. The message must be tailored for the various audiences and for varying educational levels.

Identifying and getting to know the stakeholders during this non-emergency time is imperative (USNRC, 2004). To determine the issues of concern the USNRC (2004) identifies the following as potential resources within a community: local officials, organizations representative of the area, local interest groups and local newspapers. Once the stakeholder value assessments and issues of concern are elicited, they can be used to formulate an effective risk communication plan for use if an event does occur. Providing useful and honest information before an event will build the trust and credibility, both critical attributes, needed after an event.

The USNRC (2004) identifies the following steps for building trust.

1. Provide open and honest information allowing for feedback.

2. Collaborate with a respected third party such as university faculty or local environmental groups.

3. Provide organized information and be prepared for the event.

4. Use terms and language familiar with the audience. (This point emphasizes the importance of education during the pre-emergent state. If

the audience is not educated sufficiently, it will be difficult to discuss the information appropriately.)

5. Follow through with any commitments made to the public. (This will likely be more important during the post-event phase.)

Likewise, the USNRC (2004) lists the following as actions that can degrade credibility and trust.

1. Ignoring stakeholder issues.
2. Becoming defensive.
3. Hiding information or providing misleading or incorrect information.
4. Appearing to represent only the interests of decision-makers or the government.
5. Failing to keep commitments.

The information provided above is not new. It is a compilation of many references and ideas regarding risk communication. The timing of the release of this information is unique, however. The information provided must be developed and presented *before* the event occurs and is an essential feature of the preventive or preparatory theme presented as an integral aspect of the LOI previously discussed. This is a significant departure from most references regarding risk communication. In preparation for such an event the communication begins during the pre-event phase (reference Figure 4.4). In summary, communicating the risks before the event occurs serves many purposes, the most significant of which are 1) to educate and prepare those that may be affected, 2) to coordinate the risk communication message by those that will

prepare the post-event message and 3) to decrease the impact of terrorist acts, that is, to reduce the level of social disruption and or creation of panic and chaos (Becker, 2004).

4.4.3. Post-RDE

Timing is critical to the effective dissemination, receipt and processing of the information by the audience and should be done even if all the information is not available at the time (NCRP, 2001). Uncertainties and unknown variables should be clearly identified and articulated.

A pre-planned message template should be developed so that after an event occurs the details can be filled in and the information can be released immediately. The determination of who will deliver the message is important and is likely to depend on the circumstances of the event. During the problem-formulation phase potential messengers should be identified for each region within the watershed area. The message must be:

1. Clear,
2. Concise,
3. As accurate as possible, based on available information,
4. Consistent,
5. Honest with uncertainties acknowledged, and
6. Delivered in a non-emotional manner (which may help reduce panic or fear expected from a RDE) and with appropriate language for the target audience.

Furthermore, the plan must detail who is responding, what has happened, what actions the public should take, estimates of health risks to those in the affected area and when more information will be forthcoming. The message should identify one information resource so incoming calls can be directed away from those directly involved in the response. Redirecting requests for information from outside the communication chain will allow those conducting the response to concentrate on the recovery.

An established delivery platform is essential once the event has occurred. Television, radio and print news media will likely be the most available venues. However, local authorities can be a means of dissemination and should be used because they are seen as trusted and credible (Becker, 2004). The local responsible agency must determine who and what are the most appropriate and effective methods for delivery.

4.5. Summary

The LOI process integrates ERA and HHRA. The resultant value from the LOI equation incorporates both ecological and human health risks thus allowing a direct comparison among affected regions. This provides a simplified method to prioritize recovery actions and effectively and efficiently allocate resources.

Organizations involved are identified and coordinated, the end-state is pre-identified and agreed upon, the risk communication plan is prepared and implemented and all required data and information needs are determined in the problem formulation phase. This provides an ideal framework to allow for a

preventive, precautionary response that is adaptive and flexible. The LOI allows and promotes a compilation and sharing of ideas, values and expectations so that an informed, effective and practical decision can be made.

Evaluating and assessing the radiological dispersal event in a time of calm, i.e. pre-RDE phase, has the significant advantage of *time*. Simply put, assessing a radiological release of any magnitude after the event has occurred places a significant burden on all involved and increases the level of urgency in decision-making. Preparing and planning prior to the event allows for the inclusion of all identified stakeholders. Social and economic values will be critical aspects of the resulting decisions and must be considered early.

The LOI analysis is an integrated, holistic approach that, in turn, should lead to a more effective and efficient use of resources. It provides a simple method for comparison within and between regions or sub-regions so that priorities can be set and managed in a quick, efficient manner. The pre-RDE phase requires the formulation of the scope of the scenario based on worst reasonable-case estimates (analogous to the USEPA's reasonable maximum exposure, RME, method for estimating cumulative individual risk from chronic exposure). Furthermore, the limited number of radionuclides of primary importance and their known human toxicity makes the analysis during this phase relatively simple. This will save time once the event has occurred. Once the event occurs, real-time data providing specific radionuclide information, such as radiation type, quantity, and the release point can be inserted into the pre-RDE assessment. The collection of this information will be from the DOE and USEPA during the crisis-management

phase and will supply the information normally collected during the screening-level phase of a typical ERA.

The LOI analysis is adaptive by nature because it can be tailored to each affected region and at any required or desired resolution. The approach addresses the wicked nature of a radiological release. Further components of the problem such as multiple stakeholders, unknown effects on some ecological receptors or unknown (but expected) social and economic impacts makes the integrated approach ideal (Toth and Hizsnyik, 1998).

CHAPTER 5

DISCUSSION OF LEGAL AND POLICY ASPECTS

5.1. Introduction

The previous discussion regarding the Level of Impact analysis resulted in an integrated assessment approach that allows for consideration of typically non-risk assessment parameters: socioeconomic issues, cost, actual and perceived risk and impact to ecological receptors. This approach bridges the gap between ecological and human health risk assessment approaches which are historically conducted separately and highlights the updated framework needed in the face of recovering from a terrorist event. An additional historical artifact also occurred through the course of development of environmental law: separation of the protection of human health and welfare and protection of the environment. U.S. environmental laws have been based on this separation. These two entities are routinely and as a matter of law, considered separately. The LOI approach considers them as one indistinguishable entity and places them under the same assessment umbrella from the perspective of a RDE recovery. Literature identified in Chapter 2 suggests the integration of risk assessment approaches is needed, but there is no overwhelming endeavor to do so. Protecting one entity is by default protecting the other due to their interconnectedness.

The discussion to follow will not explicitly address a solution to the separation of environment and public health and welfare because this is a subject for another study. The legal and policy framework currently available, however, needs refinement to address the issues which might arise following a RDE. The discussion to follow, then, identifies some of the legal and policy issues that must be addressed to ensure the U.S. is prepared for an effective *environmental* recovery following a RDE.

5.2. Legal issues

There are a number of executive orders (EO), regulations and presidential decision directives (PDD) covering the broad topics of terrorism and radiological response from a terrorist act. Most delineate roles and responsibilities or direct immediate actions to be taken to prevent or mitigate harm to public health and the environment. Generally, the guidance and policy regarding actions to take involving a RDE, or more frequently a radiological dispersal device, is directed toward first responders such as medical teams, law enforcement and hazardous material survey teams. Some directives distinctly call for the protection of the environment and public health but provide no specific direction as to how this will be assessed and/or implemented. There is no governing legal guidance regarding a recovery approach to take once the crisis-management phase has ended and the consequence-management phase has begun in earnest. [Homeland Security Presidential Directive 5 (HSPD 5), 28 Feb 2003, states in paragraph 3 that the U.S. Government does not treat crisis- and consequence-management as

two distinct phases. However, for the purposes of this study and delineation of the scope of responsibilities and response capabilities, these two phases are considered separate but overlapping. The crisis-management phase begins at the point the RDE occurs and continues until such time as the Department of Homeland Security and Department of Justice relinquish on-site authority to the USEPA for recovery. The consequence-management phase begins at the point USEPA assumes responsibility for further mitigation and recovery of the region. These phases may overlap because initial mitigation efforts can begin near the onset of the crisis-management phase and continue throughout this phase.] Without clear legal guidance, funding could be an issue which hampers the efficiency of the recovery.

The current directive for response to all domestic terrorism events is the National Response Plan (NRP) (DHS, 2004). This directive delineates roles and responsibilities following a radiological terrorism event without creating any new statute, regulation or changes to the legal authorities under which any agency operates. Each agency that has agreed to follow the NRP has done so by signature; the plan, therefore, is an agreement between agencies. The purpose of the NRP is to

"... establish a comprehensive, national, all-hazards approach to domestic incident management across a spectrum of activities including prevention, preparedness, response, and recovery." (DHS, 2004).

And the scope of the plan,

"Covers the full range of complex and constantly changing requirements in anticipation of or in response to threats or acts of terrorism, major disasters, and other emergencies." (DHS, 2004).

The authority of the NRP is based on the Homeland Security Act (PL 107-296), Homeland Security Presidential Directive – 5, Management of Domestic Incidents (February 28, 2003), and the Robert T. Stafford Disaster Relief and Emergency Assistance Act (PL 93-288).

The NRP outlines the support the federal government provides to state and local governments and applies to all federal agencies that may be tasked with providing support within the context of an Incident of National Significance, such as terrorism. The DHS defines an Incident of National Significance as an event that requires coordination by the Department of Homeland Security due to its nature and complexity of response, i.e. requires a multi-agency response. The plan does not, however, provide specific guidance on how to approach the recovery from a risk assessment perspective. This deficiency in the guidance was, in fact, noted and the DHS is attempting to rectify it. (A brief discussion of the recommendations included in the report released 3 January 2006 was provided in Section 4.2.1.). The resulting recommendations do not specifically address how to approach the problem from an assessment perspective. The guidance reiterates the roles and functions of the various agencies expected to be involved and delineates the legal chain of command to be followed via the NRP.

The NRP provides guidance on specific incidences and provides policies, concepts of operations and responsibilities for each of the listed annexes and agencies from a management perspective, i.e. a strategic view. A RDE falls under two of the annexes: Nuclear/Radiological and Terrorism. The Terrorism Annex addresses the investigative aspect of the incident from a legal perspective. The

Nuclear/Radiological Annex addresses the response from a technical aspect regarding chain of command and responsibilities of agencies. It does not, as mentioned, provide a useable framework whereby decision makers can begin to evaluate and compare the impact of the RDE; it simply provides a communication and response framework whereby agencies can determine their respective places in the chain of command. This is essential, for without an established chain of command the response would be chaotic. The annexes are designed so that one or more annexes can be applied simultaneously. The scope of the Nuclear/Radiological Annex covers the actual or threatened use of a radiological weapon that poses an actual or *perceived* threat to public health or the environment.

Once the responsible agencies are engaged, they are left to their own devices to determine how, within their means and technical specialties, to assess the impact of a RDE; there is no tactical guidance on how to evaluate the impact. In the case of a RDE the USEPA will eventually, during the consequence-management phase, be the lead agency. This creates a legal chasm because there is only limited guidance or policy within the USEPA on conducting the risk assessment and evaluation of the impact the RDE may or may not have. Furthermore, the legal basis for response and recovery may be questionable because it is unclear how the cleanup should be legally handled, i.e. under the USEPA's jurisdiction it is not clear what the legal driver is for conducting the assessment and subsequent cleanup. The following is a list of some potentially applicable statutes, regulations or other directives under which the USEPA is

mandated to respond to radiological emergencies during peacetime (http://www.epa.gov/radiation/rert/authorities.htm) (accessed 11/15/2005). None of the following, however, specifically address how the impact of a radiological release resulting from terrorist activity will be assessed and subsequently, cleaned up. They simply require that a plan be developed and implemented in that event and state when and how the USEPA is responsible. Again, these provide a strategic view regarding response but lack tactical application.

1. Radiological Emergency Planning and Preparedness Regulation (44 CFR 351)
2. Continuity of Operations Plan Policy (USEPA Agency Order 2030.1).
3. Federal Emergency Management (EO 12148).
4. Assignment of Emergency Preparedness Responsibilities (EO 12656).
5. Establishment of the Office of Homeland Security (EO 13228).
6. U.S. Policy on Counter-terrorism (PDD 39).
7. Protection Against Unconventional Threats to the Homeland and Americans Overseas (PDD 62).
8. Management of Domestic Incidents (HSPD 5).
9. Critical Infrastructure Identification, Prioritization, and Protection (HSPD 7).
10. National Preparedness (HSPD 8).
11. National Response Plan (NRP).

The expected default legal directive, as a result of the direction the NRP dictates, is the Comprehensive Environmental Response, Compensation, and

Liability Act of 1980 (CERCLA), as amended. Application of CERCLA in this case is not clear or without potential legal and political ramifications.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, may apply due its broad language, definitions and characterizations. Because the USEPA will have jurisdiction for oversight of the cleanup, it is reasonable to assume they will use as their model the framework provided in CERCLA. This law has been in place and used in scores of cases for remediation of sites listed on the National Priorities List (NPL) as well as many non-NPL sites. An evaluation of the applicability of CERCLA appears to indicate that it can be applied to all releases of hazardous substances, i.e., radioactive material falling within the categorization of a hazardous substance. There are various statements throughout Sections 9601, 9604, 9605, 9615 and 9618, Title 42, USC, indicating CERCLA could be applicable, and one section where it appears CERCLA is absolutely not applicable.

Application of CERCLA could be in jeopardy due to the exception for the "... release of source, byproduct, or special nuclear material from a nuclear incident." Nuclear incidents fall under the authority provided in the Atomic Energy Act of 1954. The significance of this exclusion lies in the assumption that radioactive materials likely to be used by terrorists due to availability, quantity and types are likely to be governed under the authority of the USNRC via the Atomic Energy Act of 1954. This assumption precludes the possibility of radioactive materials smuggled into the U.S. by and from foreign entities. This may lead to delays in response due to a lack of legal precedent or clear articulation within CERCLA

regarding response and remediation authority. CERCLA does not apply when the radioactive material used in a RDE is deemed to be under the jurisdiction of the USNRC or Department of Energy.

A review of the legislative history of CERLCA and USEPA's annual report on Superfund (USEPA, 2005) indicates the "intent" of CERCLA was clearly to address abandoned hazardous waste sites. It does not appear that the scope of the act was ever intended to address intentional releases such as from a terrorist act. This point makes the application of CERCLA questionable.

Although Section 9615, "Presidential Delegation and Assignment of Duties or Powers and Promulgation of Regulations", provides a mechanism whereby funds can be drawn for use and transferred as needed to other agencies, these funds must be reimbursed. This raises a possible point of contention. Chemical and petroleum companies and corporate environmental taxes contributed the majority of funds (approximately 66% of the total revenues for the period FY 1991 through FY 1995) to sustain cleanup activities under CERCLA until the end of 1995 (McCarthy, 2003). Additional funds were contributed annually through Congressional appropriations. The remaining revenues were obtained through cost recovery (8.2%), fines and penalties (0.1%), interest on investments (9.1%) and general revenues (16.8%). The taxation policy was by design because these companies were considered the most likely to have contributed to hazardous material releases.

There is certainly the very likely possibility of an emergency appropriation by Congress under which USEPA could conduct the remediation. This has been the

case during numerous domestic natural disasters and occurs when the governor of a state requests federal assistance through the DHS via the Federal Emergency Management Agency (FEMA). Appropriations of this type, however, are not budgeted and, therefore, ultimately result in a reduction of expenditures in other, previously budgeted, areas. Reacting in this manner appears, anecdotally, to result in overspending and underutilizing available resources. One needs only read the news reports on the response to Hurricane Katrina, which occurred in August 2005, to see how allocation of resources were, reportedly, inefficiently managed. Emergency appropriations may be an accepted practice for one-time, rare events, but what if terrorism, as some reports forecast, becomes more common? Appropriating funds reactively is certainly not a practical solution.

Recovery of costs is ambiguous in the case of a terrorist act because it seems highly unlikely that affixing blame and clearly identifying a potentially responsible party will occur. Should a party claim responsibility for the act, the legal channel for cost recovery is not likely to end with success. Therefore, tapping the fund for immediate use, seemingly possible as noted above, would result in depletion of an already shrinking fund and without clear guidance on how these funds will be replaced, could significantly hamper the response. At present, funds are deposited annually by Congressional appropriation and, when costs can be recovered, through identification of potentially responsible parties. The average annual contribution from Congressional appropriations was $1.3B for the periods FY2000-FY2004 (USEPA, 2005). McCarthy (2003) indicated the fund had a projected balance of $159M at the end of FY 2003. This value

represents uncommitted funds that are potentially available for an emergency response.

In summary, CERCLA does not explicitly address cases where hazardous materials are released due to the actions of terrorists. However, the broad language contained in CERCLA makes it seemingly applicable to a RDE due to the powers provided to the President due to emergency actions. Under Section 9604 the President can direct actions to be taken if it is determined the RDE presents an, "imminent and substantial danger to the public health or welfare." It is under this authority that the President can direct recovery and remediation under CERCLA without modification to the act as currently written. A response under this provision is not without problems, however. There is a limitation regarding expenditure and time commitment for emergency actions. Under the provisions of Section 9604 there are two restrictions regarding emergency responses: one, the response is limited to $2M and, two, the response can not exceed a year from the date of initial response (Reisch and Bearden, 1994; 42 USC, Section 9604(c)(1)). Based on the average amounts spent on cleanup of sites (approximately $16M) mentioned in Chapter 2, the $2M cap will certainly not be adequate.

5.3. Policy

5.3.1. Introduction

Nuclear policy development has long been difficult for U.S. legislators. Reactor siting, waste repository development, shipping of waste, and weapons development, to name a few, have all been targets of criticism. The "unknown" and "fear and dread" perceptions of nuclear technology inhibit the successful resolution of these issues. This might be the case for policy regarding a RDE, but this should not deter decision-makers from undertaking this essential task. Nearly 50 years after the first U.S. commercial reactor went on-line, the U.S. still has not fully implemented its national policy regarding reactor waste disposal. (The Nuclear Waste Policy Act of 1982 (PL 97-425) requires the U.S. to develop a repository for spent nuclear fuel. At present Yucca Mountain, Nevada, has been designated as the long-term storage site for spent fuel and high level radioactive waste. However, final community acceptance, dispute resolution and licensing issues are still pending.) The solutions to our nation's nuclear waste disposal problems are not necessarily technical but are likely more political and social in nature (Dunlap *et al.*, 1993); this same situation is likely true for dealing with a RDE.

The addition of terrorism only complicates the issues. Beyond the lack of clear practical or legal guidance for recovery after a RDE is the wicked nature of the combined characteristics of a radiological and terrorist event. This combination produces aspects heretofore unseen. Taming the wickedness, therefore, is a critical step in developing a comprehensive approach to recovering

from a RDE. An audience's acceptance of a subject is directly proportional to their familiarity with it which is, in turn, in direct proportion to the education they have received on the subject (NCRP, 1994).

Policy-makers are faced with the historically precautionary practice of setting residual contamination levels at factors of 100 to 1000 times less than those known to cause scientifically verifiable, biological effects in animals, thereby nearly guaranteeing no ill effects. On the other hand, setting policy for response to terrorism is a relatively new exercise without a substantial level of precedence. Establishing local, state or federal policy is not an exact science, nor are there models whereby all aspects of the proposed policy can be assessed. Stakeholder wants and desires and ensuring public health and welfare and ecological safety, i.e. *environmental* safety in the new sense of the word, must be given due consideration.

The following discussion presents the major issues for policy consideration and those that are considered critical to development of an effective state and/or federal policy. The key factors are flexibility and adaptability, education, planning and preparation, waste, changes to current law (CERCLA), risk communication and radiation dose levels.

5.3.2. Flexibility and adaptability

A radiological terrorism policy dealing with environmental recovery must be flexible and adaptive to regional needs due to the inherently complex nature of this scenario. Flexibility and adaptability are essential when dealing with wicked

problems. The proposed policy must allow for regional variations and allow for decisions to be made somewhat autonomously, i.e. without rigorous oversight by disjointed hierarchies and burdensome bureaucracies that can hinder the recovery. This approach is supported by the Department of Homeland Security (Conklin, 2005).

There are multiple parameters requiring consideration (see the LOI discussion in Chapter 4) and none can be dismissed without consent and agreement of affected stakeholders. As previously discussed, dealing with such intractable problems requires adaptability. The integrated LOI assessment in Chapter 4 provides an adaptable and flexible process that allows for multiple parameter consideration. The policy cannot be too restrictive or complicated nor can it be overly precautionary, because this can inherently decrease its flexibility and adaptability. Any idea of framing recovery based solely on exposure or dose limits to potentially exposed individuals might limit the practicability of a policy. Short-term policy planning, while most likely needed due to the increasing probability of such an event, is not the optimal solution. What is needed is a long-term, socially integrated approach based on education, planning and preparation -- all of which should be grounded in accurate scientific information.

5.3.3. Education

Education is a key to combating the wicked nature of the RDE. It should start in the basic sciences during the formative years and continue through college. The subject matter can focus on radiation sciences but could also include

biological and chemical uses in terrorism. The subject of terrorism could also be introduced and explored so that familiarity is gained and the goals of the terrorist are better understood. This could reduce the level of anxiety and fear associated with these topics and better prepare the coming generations for what appears to be a commonplace occurrence in our world.

Education of stakeholders with regard to ionizing radiation and its relative risk will lead to familiarity over time and a more rational, measured response to any terrorist attack using radiological devices. Educational changes within science curricula should be considered. As an example, the *Science Academic Content Standards*, developed by the Ohio State Board of Education and the Ohio Board of Regents, retrieved December 7, 2005, from http://www.ode.state.oh.us/academic_content_standards/ScienceContentStd/PDF/SCIENCE.pdf, identifies radiation in the *Scope and Sequence* portion of their 311-page academic standards as an explicit study point for 12th graders, although it can be found in the sections describing standards for grades 9-11 as well. Within this document the term "radiation" is found 37 times, and all 37 instances are within the context of electromagnetic or thermal radiative properties. A search for the term "decay" resulted in 20 instances. Within this context radioactive decay is discussed. A search of the terms "effects" (59 instances) or "biological effect" (0 instances) demonstrates that within these contexts ionizing radiation is not addressed. The point of this discussion is that students in secondary education programs in Ohio, and likely across the country, are not presented with scientific information regarding biological effects of ionizing

radiation. These students do not receive training requisite to assessing or understanding the relative risks of ionizing radiation. Once a student enters post-secondary education, only specialized, higher-level science courses, if selected, present information regarding ionizing radiation and its biological effects. Presenting this information at an early point in a student's academic career will lay the groundwork for understanding and familiarity. The focus of the education does not have to be acceptance of nuclear power or nuclear warfare, but rather an unbiased, scientific depiction of the interaction of radiation with matter and the associated known biological and ecological effects. Familiarity with a subject will decrease the fear. Slovic (1987) identified subjects of significant "fear and dread" as those that are unfamiliar or unknown and, vice versa, those that are less feared as those that are well understood or those with which one is familiar. The National Academy of Engineering (2002) notes that Americans, in general, are not adequately prepared to accept and understand technological change and that they are not, in fact, "technologically literate." Technological literacy, they state, "...encompasses at least three distinct dimensions: knowledge, ways of thinking and acting, and capabilities." They argue that society as a whole, including decision-makers, can benefit from improved technological literacy through a higher level of awareness and understanding. Costs and benefits can be weighed and decisions made that will provide a net benefit to society. This can only be accomplished through education, awareness and understanding; all of which start at an early age.

5.3.4. Planning and preparation

Planners must expand their scopes of scenario planning and preparation to include more non-explosive releases such as the case considered herein. Cases involving radiological materials dispersed with explosives potentially generate more casualties (from the blast), air releases (from the blast) and more widespread contamination (from the blast) than a release of radioactive material in a water medium. However, the economic, social and psychological effects are likely to be just as significant. Because very few scenarios involving a radiological dispersal device (explosive or otherwise) are likely to cause significant short- or long-term human health effects from radiation exposure (Steinhausler, 2005), planning must be focused on the social and ecological aspects neither of which is limited to releases from explosive devices.

Vulnerability assessments are mandated for critical infrastructures, of which water distribution systems are one, by the *Public Health Security and Bioterrorism Preparedness and Response Act* (PL 107-188). These assessments could conceivably be extended to include areas that affect the critical infrastructures, e.g. water sources feeding the water distribution or treatment systems. Rivers, lakes, streams and ground water feed the water infrastructure; it is logical, then, that these ambient sources of water should be assessed before they reach the public system. If the contaminant can be prevented from reaching the man-made distribution system then the system can be spared contamination, and it might prove to be more cost effective to address the problem at this level rather than within the expensive distribution system. Assessing at this level also

prevents shut down of the system before it reaches a critical point of contamination. Identification of the contaminant before it reaches the infrastructure system will allow time for preparation of alternate water sources or treatment and distribution systems.

Monitoring is an obvious basis for identifying and quantifying the extent of any contaminant release. Baseline data is critical for determining the risk posed by a release of radioactive material. Without regional baseline or background data verification of a release is difficult. This is due to the varied background levels of radiation throughout the country. Radiation levels can vary by an order of magnitude. While the network of real-time data monitoring provided by the United States Geological Survey (USGS, 2005), USEPA and state Environmental Protection Agencies, among others, is impressive, it is insufficient for radiological monitoring. Current real-time data monitoring is primarily concerned with general water chemistry, e.g. pH, temperature, turbidity, dissolved oxygen. These indicators are essential for determining the presence of chemical or biological contaminants but might not be as sensitive to radiological releases due to the extremely large concentrations of material required for acute effects. The network of monitoring must, therefore, be extended. A process of prioritization and site selection will be needed because the capital investment for the instrumentation, data accumulation and analysis could be substantial for aquatic monitoring. As indicated in Figure 4.7, if these costs are considered prior to the RDE, purchased and installed, costs can be amortized over time to reduce the

bolus expenditure after the event. Moreover, once the event has occurred deployment of monitoring equipment would not provide reliable baseline data.

The model of investigation and research established by the CDC (Becker, 2004) for the investigation of risk communication is ideal for planning and preparedness. The DHS, in consultation with the Department of Justice, should identify a list of potential areas of significance, i.e. those potentially seen as attractive to terrorists, and award grants to academic institutions (or national laboratories) for the development of impact analyses for these areas. Each award recipient could be provided the general LOI model for use and charged with the identification of stakeholders, exposure pathways and economic and social factors and with the need to generally define the impact parameters unique to that area. This format may serve to refine and enhance the effectiveness of the approach through the identification of uncertainties, as yet unforeseen, and the development of improved assessment techniques. The cumulative gain in knowledge can be fed back into the educational system for dissemination. The cost of the assessments is likely to be much lower by using these institutions than by hiring contractors. There may be issues of national security, and this must be further investigated to ensure proper protection and oversight is provided.

For the case study recommended in the next chapter the following information is useful and indicative of what might be needed regarding additional monitoring. The Miami Conservancy District (MCD), with headquarters in Dayton, OH, recently completed a study of the water quality of the Mad River Watershed (MCD, 2004). There are currently 33 wells located in the aquifer system, and

each of these was used as a sampling point. Three radionuclides are currently on the list of parameters evaluated: Radon-222, Hydrogen-3 and uranium (presumably 238). These may serve as possible indicators of increased contamination, although their energy and radiation emission signatures are not representative of radionuclides thought to be viable options for a terrorist event (Ferguson *et al.*, 2003). With this in mind, the historical and background or baseline data currently available is of limited usefulness. Additional sampling locations are located in the City of Dayton well-fields (City of Dayton, 2005). There are currently 160 early warning monitoring stations and 58 investigatory wells that are used when needed. These stations are used to monitor for increases in contamination of the aquifer system. To be useful as background data, daily or weekly real-time data of gross gamma counts is needed to monitor variation. Further enhancements would include monthly alpha and beta measurements, although these would require laboratory analysis due to the attenuation provided by the water. The currently existing well locations provide an ideal location for sampling. A real-time gross gamma counting system could be installed in the wells at costs ranging from several thousand to tens of thousands of dollars depending on the specifics of the system deployed. The MCD and Ohio EPA both have monitoring wells that can be accessed and retrofitted with real-time data monitoring equipment.

5.3.5. Waste

Because the waste generated from remediation can be significant and, therefore, expensive to dispose of, a policy must be implemented of guaranteed acceptance at nominal fees of generated wastes from a RDE at any of the low-level radioactive waste sites. This will reduce a substantial portion of the cost of remediation and is a factor that must be considered (Gonzalez, 2005). Because the cause of the release is non-commercial, the cost should not be shouldered completely by the affected region because this could bankrupt the area. Spreading the cost also will defray the local economic impact and minimize the terrorist's intended economic disruption. Steinhausler (2005) has suggested the idea of local storage of generated wastes in order to reduce potential personnel exposures and reduce accidents during transportation. This could provide a short-term logistical respite but should not be the long-term solution. Residents are not likely to accept a disposal site within the immediate area in addition to being victims of a terrorist act. Additionally, development of a disposal site will require a significant level of evaluation, licensure through the USNRC and a risk assessment to determine if siting is appropriate; this could present a potential delay in recovery actions.

5.3.6. Legal changes

Much discussion has been published regarding the potential legal issues surrounding a radiological terrorist act (Elcock *et al.*, 2004; Conklin, 2005). As this does present a significant hurdle, including a RDE under CERCLA will

eliminate legal guesswork and provide a reasonable framework under which the USEPA can operate. Although CERCLA does not currently appear to apply directly to cases of terrorism, the USEPA will be the lead agency and as such will likely turn to in-place rules, regulations and laws for guidance during cleanup. Because none of the current regulations explicitly cover terrorism, CERCLA is a logical choice (see previous discussion in Section 5.2) to address cleanup. Therefore, a line item change in CERCLA to include terrorist acts and the subsequent cleanup should be considered or the exemption found at paragraph 22, Section 9601, Title 42 USC, should be changed to include radioactive material releases from a terrorist act. There is recent activity within the U.S. Senate regarding vulnerability of chemical plants to terrorism from chemical and biological agents. In some of the proposed verbiage, CERCLA is specifically addressed. This may provide a precedent for applying CERCLA to terrorist acts. If an act such as those being considered is enacted, a change to CERCLA might not be required.

An alternative option would be to create a Superfund-like account within the Department of Homeland Security (DHS) to be used for recovery and remediation following radiological terrorism. As in the case of the initial deposit into the original Superfund by Congress, an appropriation to start the DHS fund would be appropriate. Average annual appropriations are likely to be needed to support DHS-governed remediation. These types of appropriations are currently a major funding source for CERCLA cases. Average appropriations to the Superfund for the last five years have been $1.3 billion (USEPA, 2005). An extension of the

funding issues and continued research and development in this area can be investigated through academic grant programs such as those discussed in the next section.

5.3.7. Risk communication

As previously noted, the CDC (Becker, 2004) has undertaken research responsibility for development of risk communication plans prior to terrorist acts by awarding research grants to academic institutions. Also previously discussed is the need for development of a risk communication plan that focuses on the pre-event message but that provides continuity throughout all phases of the recovery, response and remediation. The CDC funded research is a leap forward from previous risk communication efforts, but is short of the mark. A key aspect of the presented risk communication plan is the *release* of well-developed, fact-based information *before* an event occurs. The CDC advocates development of the material prior to the event but awaiting release of the information until after the event has occurred. Furthermore, the risk communication plan must be flexible enough to allow for real-time updates and/or changes, but must maintain a consistent message throughout all phases. Expanded research in this area is crucial.

5.3.8. Radiation dose levels

The last consideration is that of acceptable radiation dose levels. Although dose levels to affected populations are not specifically addressed in this study it is a subject that must be considered to some degree when dealing with radiological terrorism. Currently, there are no nationally or internationally established acceptable dose levels following a RDE. Determination of appropriate and acceptable cleanup levels, based on the dose to occupying biota, possibly higher than currently accepted public levels but less than the occupational dose limits (epidemiology studies show no increase in lifetime cancers from occupationally exposed population, so this level appears to be adequately safe – for this scenario) may be an option. The current general-public dose levels might be too restrictive for an area affected by a RDE, and, therefore, a mechanism whereby these can be relaxed should be established. Recently proposed Protective Action Guides (Conklin, 2005) support this premise. Conklin (2005) further states that due to the time constraints immediately following a radiological release stakeholder input will likely be minimal. As presented in the LOI discussion, this is a significant point of consideration during the *problem formulation in the pre-event phase* and not an item that should be left for consideration after the event. This will allow critical, stakeholder input, discussion and agreement before the event occurs, thereby reducing post-event delays due to unresolved issues. Consideration of stakeholder issues *before* the RDE represents a significant difference in the current approaches to risk assessment and disaster management in general, and is one of the focal points of the proposal.

5.4. Summary

There is a need for legal and policy development in preparation for the possibility of a RDE. An effective recovery will be hampered if the legal framework does not clearly identify the basis for recovery. Because CERCLA, the assumed regulatory driver for a cleanup after a RDE, is not clear with regard to its application in this situation, a change to the verbiage should be considered. This change should address funding of the cleanup and address the level of cleanup based on soon-to-be-released DHS guidance (Conklin, 2005).

A policy of education reform must be adopted to address the issue of technological literacy. Science training and education must provide a sound foundation in the formative years so that future stakeholders will be prepared to make appropriate risk comparisons. The risk communication pre-event message is required to ensure the right information is released at the right time. Pre-released information will educate and familiarize stakeholders with the basic concepts of ionizing radiation and terrorism, thereby reducing the socioeconomic impact of a RDE. Scenario considerations must be expanded to consider situations such as a RDE within a water medium in order to better prepare communities for many other emergency situations.

CHAPTER 6

RECOMMENDATIONS FOR FUTURE RESEARCH

6.1. Introduction

As a result of this study, many potentially interesting research topics have arisen. A list of these will follow in Section 6.4, but the prominent topic is an application of the LOI approach to the Mad River Watershed (MRW). The MRW was selected due to its designation as a model for watershed management and well-field and source-water protection by the Ohio EPA and USEPA. In this chapter an expanded recommendation is given for future research based on preliminary data gathered on the MRW. Presented below are some of the basic hydrogeology aspects of the area, its unique institutional framework and a preliminary, proposed organizational framework for recovering from a RDE within the MRW. The culmination of this research would be a complete analysis of anticipated environmental, economic and societal impacts from a RDE and a definitive hierarchy of regional organizations, their respective roles and how they could be best integrated for an efficient recovery.

6.2. Overview of Mad River Watershed

The Mad River Watershed (MRW) is an important hydrogeological entity in that it is a major recharge source for the Great Miami Buried Valley Aquifer System (Figure 6.1.). This aquifer system was designated a Sole Source Aquifer in 1988 by the U.S. Environmental Protection Agency (USEPA). Drinking water, industrial withdrawals and recreational activities can all be impacted from a RDE within the MRW. Additionally, the location of Wright-Patterson Air Force Base (WPAFB) in the southeastern portion of the MRW, and adjacent to the constructed aquifer recharge area, makes this area potentially strategically vital from a homeland security perspective.

The MRW (Figure 6.2.) lies within the Ohio counties of Logan (head waters), Champaign, Clark, Miami, Greene and Montgomery and is a major tributary watershed within the Great Miami River Basin, draining an area of approximately 657 square miles (MCD, 2004). There are three major aquifer systems within the MRW: buried valley, carbonate bedrock and discontinuous upland sand and gravel till (MCD, 2004). The principal aquifer within the basin is a buried valley system of sand and gravel aquifers which can provide well yields greater than 1,000 gallons/minute (Debrewer, *et al.*, 2000; Dumouchelle, 1998). The aquifer is the principal drinking water source for approximately 1.6 million residents (approximately 90% of the regional population) and is the dominant source of water in southwestern Ohio (Dumouchelle, 1998; Yost, 1995).

Much of the buried valley aquifer system lies within the Mad River Interlobate Area which originated during the last glacial advance into

southwestern Ohio. At that time the watershed was subjected to sand and gravel deposition from glacial meltwater because it was positioned between two large lobes of ice (MCD, 2004). The majority of the consolidated deposits are Ordovician, Silurian and Devonian sedimentary rock systems. This is significant because the geologic composition of the area governs the transport and storage of, biogeochemical interactions and surface water and ground water interaction (Debrewer, *et al.*, 2000). For example, some areas within the aquifer system are impermeable shale (Ordovician) and some parts are more permeable (Silurian/Devonian) meaning recharge of the aquifer varies significantly throughout the system (Debrewer, *et al.*, 2000). This point is significant when attempting to plot plume transport and predict areas of potential deposition. Where interaction with the aquifer is unlikely due to geologic formation, radioactive contaminants in surface water can be transported and/or deposited surficially or continue longer distances through surface water transport. This may present a more immediate ecological or human health hazard because the exposure potential for the radioactive material is greater due to the proximity of biota to the contaminant and decreased retention time of the radioactive material. The latter point could be significant due to physical decay of the radionuclide. Retention within the ground water system could serve to reduce radioactive emissions by many orders of magnitude depending on the specific radionuclide released.

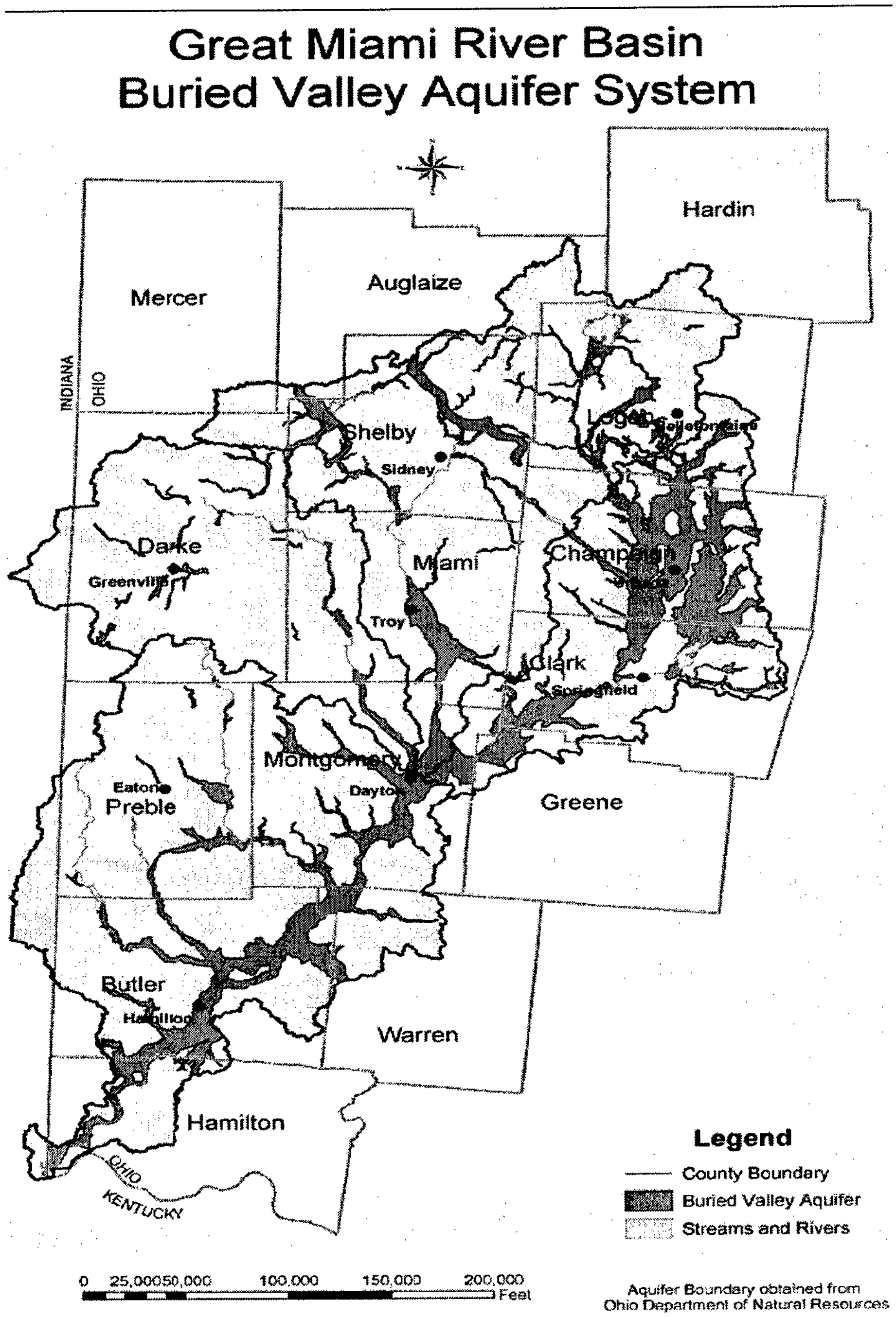

Figure 6.1. Great Miami River Basin Buried Valley Aquifer System. (Retrieved February 6, 2006 from http://www.miamiconservancy.org/water/aquifer_what.asp)

6.3. Organizational Framework within the Mad River Watershed

The Miami Valley enjoys a unique institutional framework due to its long-standing history resulting from the Flood of 1913. As a result of this flood the Miami Conservancy District (MCD) was created to begin development of flood control programs. Since its creation this agency has become vitally important throughout the region in many areas regarding flood control but also in watershed management. The application of the LOI approach within the MRW would certainly require the coordination and expertise available at the MCD.

Another important organization within the Miami Valley is the Miami Valley Regional Planning Commission (MVRPC). This organization conducts and provides resources for regional planning and development. They are also intimately involved in environmental planning and in response and recovery programs. Both the MCD and the MVRPC are developing their Geographical Information System databases which are and will continue to be essential to watershed mapping, ground and surface water modeling and environmental recovery applications.

Additional city, state and federal organizations that are likely to be involved in the recovery actions following a RDE are many. Further research could assist in determining all appropriate organizations, their functional roles and areas of potential collaboration. One of the key groups is the decision group.

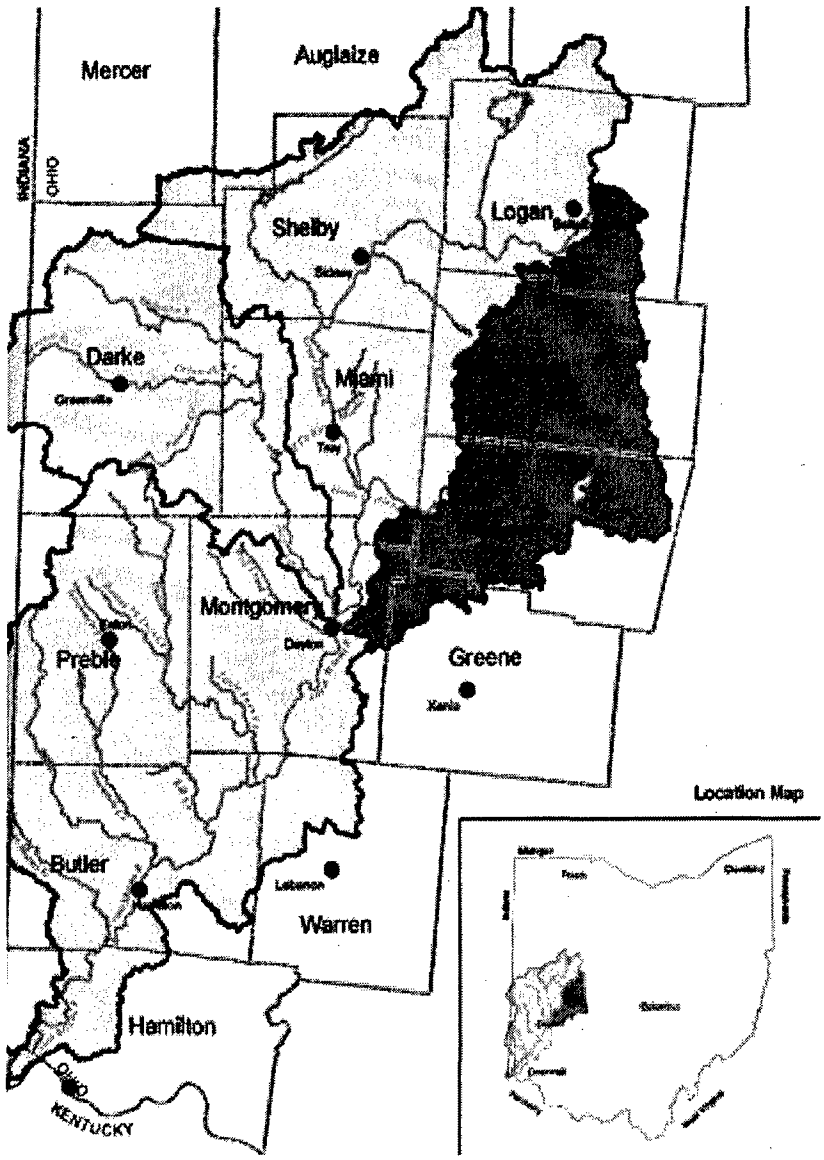

Figure 6.2. Physical location of Mad River Watershed (red area) within the Great Miami River Watershed (gray area) (MCD, 2004).

The Decision Group (Conklin, 2005) for a RDE begins at the federal level with the Department of Homeland Security (DHS). Considering the political framework within Ohio and the MRW, a preliminary hierarchy may appear as presented in Figure 6.3. These individuals are responsible for the safety and well being of the residents and have the ability to commit resources to that end. The DHS Secretary, or designee, will communicate directly with the Governor, USEPA (who will, in turn, communicate with the Ohio EPA), city and county commissioners and the Mayor, and the WPAFB Commander. This group will constitute the Decision Group. They will be responsible for making final decisions and allocating resources.

Once the consequence-management phase has been initiated, the USEPA will be the lead agency. It is expected they will defer as much of the responsibility as possible to the Ohio EPA because it is the USEPA's practice to support resolution at the lowest possible level. The Ohio EPA will likely be the agency responsible for managing the recovery with substantial funding from the USEPA and DHS. The Ohio EPA has many resources available for technical and political support. The agencies listed as being subordinate to the Ohio EPA will play a major role in the problem formulation phases as well as during the recovery. The support agencies expected to be essential to an effective recovery are the:

1. Miami Conservancy District (MCD),
2. Miami Valley Regional Planning Commission (MVRPC),
3. U.S. Geological Survey (USGS),
5. Ohio Emergency Management Agency (OEMA),

6. Ohio Department of Natural Resources (ODNR),
7. Ohio Department of Health (Bureau of Radiation Control) (ODH), and
8. City of Dayton, Environmental Management, Division of Water.

The OEMA and OHS roles are expected to be minimal during the consequence-management phase. However, they possess technical resources that may be useful and are, therefore, included in the list. The USGS, MVRPC, MCD and ODNR maintain Geographical Information System (GIS) mapping databases which will be critical to evaluating the extent of any plume migration laterally, vertically and temporally. The MCD and MVRPC provide a wealth of information resources regarding the local economy, industrial bases, institutional framework and significant political weight.

The final group of individuals is the stakeholder/resident group. Although they are not in the formal decision group, they are vitally important throughout the entire assessment process. Their role, noted in the problem-formulation phase of the LOI (see Chapter 4), is significant. There are several watershed groups within the Miami Valley. The MCD maintains a master list of these groups.

Consideration of the various land uses is important when evaluating the impact from a RDE. In addition, the numerous social and economic parameters within the Miami Valley must be identified in order to accurately estimate the impact. Within the Great Miami River Watershed, 80% of the land is used for agriculture, 12% is residential, industrial and commercial, 4% is forested and 1% is water (MCD, 2005). The primary agricultural crops are corn, soybeans and wheat (MCD, 2004). There exist a number of industrial, educational and medical

facilities, to name a few, that are likely to be impacted following the release of radioactive materials. These will need to be identified. A partial listing of data needs and resources for accessing those data are provided in Table 6.1.

Furthermore, the impact on communities down range from the RDE must be considered. For example, where industrial activities, or nodes, have potential impact beyond the immediate release area, these must be identified and investigated. An example of such a node is a paint manufacturing facility located within the MRW. A facility such as this uses water that may be contaminated following a RDE. The product of the plant is then distributed to various parts of the country. The impact of this distribution is an important factor in the economic parameter, E_i, noted in the LOI equation.

6.4. Further Recommendations

The following four additional research topics would be useful in further evaluating the impact of a RDE. The result of each of these studies would serve to further develop the LOI concept and/or provide some of the critical information needed to conduct a region-specific analysis.

1. Conduct a study to determine the perception of risk from a RDE within the Mad River Watershed.

2. Develop educational material for elementary and secondary schools with programs focusing on terrorism and the basics of ionizing radiation.

Data Need	Organizational Resource
Hydrogeologic formation	USGS; ODNR; Ohio EPA; MCD; MVRPC
Well monitoring data	USGS; Ohio EPA; MCD
Transport models	Ohio EPA; USGS; EPA; DOE
Radionuclide(s) released (type, quantity, form)	DOE; EPA; ODH
Ecological receptors (particularly those sensitive to radiation)	ODNR; Ohio EPA; OSU; DOE
Weather	U.S. Weather Service
Land use	MVRPC
Population demographics	MVRPC; U.S. Bureau of Census
Economic data	MVRPC; Dayton Chamber of Commerce

Table 6.1. Data resources within the Miami Valley, OH. (USEPA = U.S. Environmental Protection Agency; DOE = Department of Energy; Ohio EPA = Ohio Environmental Protection Agency; MCD = Miami Conservancy District; MVRPC = Miami Valley Regional Planning Commission; USGS = U.S. Geological Survey; OEMA: Ohio Emergency Management Agency; ODNR = Ohio Department of Natural Resources; ODH = Ohio Department of Health; OSU = Ohio State University)

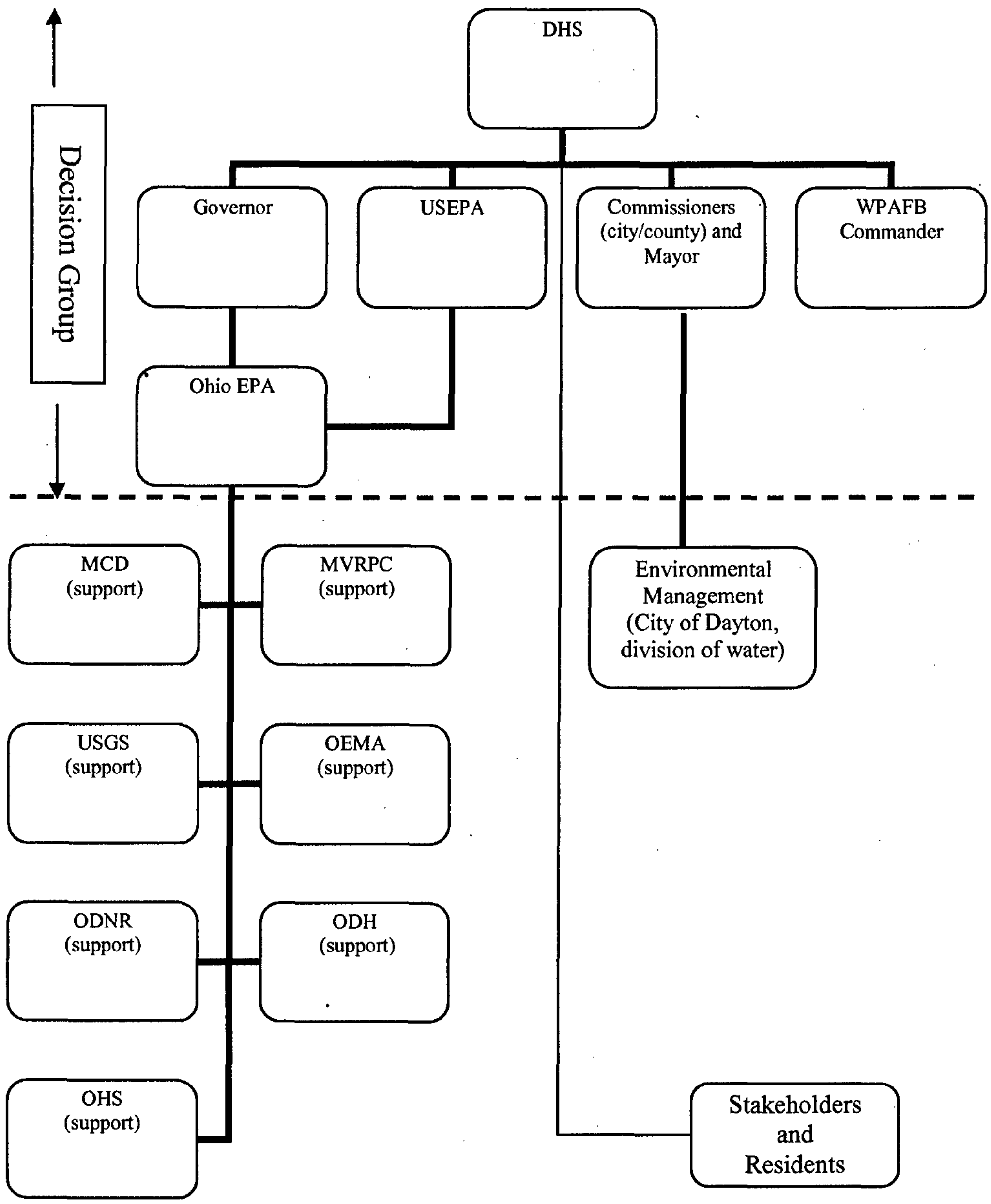

Figure 6.3. Possible organizational structure for integrated federal, state and local agency collaboration in the case of an RDE near Dayton, OH. (DHS = Department of Homeland Security; USEPA = U.S. Environmental Protection Agency; WPAFB = Wright-Patterson Air Force Base; Ohio EPA = Ohio Environmental Protection Agency; MCD = Miami Conservancy District; MVRPC = Miami Valley Regional Planning Commission; USGS = U.S. Geological Survey; OEMA: Ohio Emergency Management Agency; ODNR = Ohio Department of Natural Resources; ODH = Ohio Department of Health; OHS = Ohio Homeland Security)

3. Evaluate the application of the LOI approach to chemical and biological agents released. Determine the limitations of the problem formulation phase based on the variety of agents possible.

4. Evaluate the full capability of available Geographical Information System (GIS) modeling with respect to a RDE, and then based on the current capabilities, determine how GIS technology might affect the LOI analysis within a watershed.

CHAPTER 7

CONCLUSIONS

Many have noted the need for an integrated process in general, environmental risk assessments. This need is greater when using the process to address the recovery from a radiological dispersal event (RDE) due to the inherent wickedness of the problem. The developed Level of Impact (LOI) Analysis introduced in this study addresses this need. The LOI model presented provides a novel methodology whereby the impact from a RDE can be effectively evaluated. Highlighted within the model are the requirements for a pre-developed risk communication plan, a pre-event assessment, and early stakeholder identification and involvement.

The model is the first of its kind for such an application, and therefore addresses many of the issues expected to arise should such an event occur. The proposed methodology is a significant step forward in that it has potential application to other terrorist acts involving a variety of contaminants as well as to industrial releases that pose an imminent danger to the environment. It integrates the ecological and human health segments of an assessment into one *environmental* aspect, i.e. it is holistic in nature. This approach can result in a more effective allocation of resources during recovery based on the pre-event

assessment that provides a means whereby expected resource expenditures can be planned for and amortized.

The model incorporates elements of perceived risk and social and economic aspects from the pre-event through the post-event phases. The conceptual model introduces, for the first time, an integrated approach to assessing the impact from both ecological and human health perspectives. The model is flexible and adaptable, both of which are requisite to dealing with wicked problems such as those caused by a RDE. Throughout the assessment, new data or information can be inserted into the model, or adjustments can be made within the initial problem-formulation construct. The success of this methodology is contingent on pre-event preparation, which is a unique application of an assessment model.

An analysis of the Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended, revealed a potential failure of the Act to apply. Since the USEPA will have jurisdiction over the recovery phase of a RDE, this is a significant finding of the study. If the Act is applied, use of the Superfund for recovery may be an issue. Proposed changes to the law, including funding considerations, were presented.

Several policy recommendations were presented that must be considered for an effective recovery from a RDE. These recommendations are long-term considerations and, therefore, must be undertaken as soon as practical to allow time for adequate preparation for such an event.

Finally, a line of recommended future research was presented by concentrating on an application of the model within the Mad River Watershed

(MRW). The MRW is an important hydrogeological feature due to its designation as a sole source aquifer, proximity to Wright-Patterson Air Force Base, industrial base, and recreational venues.

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APPENDIX

(Supporting Citations from CERCLA)

The following citations, provided in Sections 9601, 9604, 9605, 9615 and 9618, Title 42 of the U.S. Code, are provided for review and in support of discussions regarding CERCLA applicability in Chapters 2 and 4. (The numbers and/or letters provided in parentheses are the subsections where the quotes are located.)

> §9601 (8) "The term 'environment' means (A) the navigable waters, the waters of the contiguous zone, and the ocean waters of which the natural resources are under the exclusive management authority of the United States under the Magnuson-Stevens Fishery Conservation and Management Act [16 U.S.C. 1801 et seq.], and (B) any other surface water, , drinking water supply, land surface or subsurface strata, or ambient air within the United States or under the jurisdiction of the United States."
>
> (9) "The term 'facility' means (A) any building, structure, installation, equipment, pipe or pipeline (including any pipe into a sewer or publicly owned treatment works), well, pit, pond, lagoon, impoundment, ditch, landfill, storage container, motor vehicle, rolling stock, or aircraft, or (B) any site or area where a hazardous substance has been deposited, stored, disposed of, or placed, or otherwise come to be located; but does not include any consumer product in consumer use or any vessel."
>
> (12) "The term '' means water in a saturated zone or stratum beneath the surface of land or water."
>
> (14) "The term 'hazardous substance' means (A) any substance designated pursuant to section 311(b)(2)(A) of the Federal Water Pollution Control Act [33 U.S.C. 1321(b)(2)(A)], (B) any element, compound, mixture, solution, or substance designated pursuant to section 9602 of this title, (C) any hazardous waste having the characteristics identified under or listed pursuant to section 3001 of the Solid Waste Disposal Act [42 U.S.C. 6921] (but not including any waste the regulation of which under the Solid Waste Disposal Act [42 U.S.C. 6901 et seq.] has been suspended by Act of Congress), (D) any toxic pollutant listed under section 307(a) of the Federal Water Pollution Control Act [33 U.S.C. 1317(a)], (E) any hazardous air pollutant listed under section 112 of the Clean Air Act [42 U.S.C. 7412], and (F) any imminently hazardous chemical substance or mixture with respect to which the Administrator has taken action pursuant to section 7 of the Toxic Substances Control Act [15 U.S.C. 2606]. The term does not include petroleum, including crude oil or any fraction

thereof which is not otherwise specifically listed or designated as a hazardous substance under subparagraphs (A) through (F) of this paragraph, and the term does not include natural gas, natural gas liquids, liquefied natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas)."

(15) "The term 'navigable waters' or 'navigable waters of the United States' means the waters of the United States, including the territorial seas."

(16) "The term 'natural resources' means land, fish, wildlife, biota, air, water, , drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States (including the resources of the fishery conservation zone established by the Magnuson-Stevens Fishery Conservation and Management Act [16 U.S.C. 1801 et seq.]), any State or local government, any foreign government, any Indian tribe, or, if such resources are subject to a trust restriction on alienation, any member of an Indian tribe."

(22)" The term 'release' means any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance or pollutant or contaminant)…" and,

"… excludes …(C) release of source, byproduct, or special nuclear material from a nuclear incident, as those terms are defined in the Atomic Energy Act of 1954 [42 U.S.C. 2011 et seq.], if such release is subject to requirements with respect to financial protection established by the Nuclear Regulatory Commission under section 170 of such Act [42 U.S.C. 2210], or, for the purposes of section 9604 of this title or any other response action, any release of source byproduct, or special nuclear material from any processing site designated under section 7912(a)(1) or 7942(a) of this title."

(23) "The terms 'remove' or 'removal' means the cleanup or removal of released hazardous substances from the environment, such actions as may be necessary taken in the event of the threat of release of hazardous substances into the environment, such actions as may be necessary to monitor, assess, and evaluate the release or threat of release of hazardous substances, the disposal of removed material, or the taking of such other actions as may be necessary to prevent, minimize, or mitigate damage to

the public health or welfare or to the environment, which may otherwise result from a release or threat of release. The term includes, in addition, without being limited to, security fencing or other measures to limit access, provision of alternative water supplies, temporary evacuation and housing of threatened individuals not otherwise provided for, action taken under section 9604(b) of this title, and any emergency assistance which may be provided under the Disaster Relief and Emergency Assistance Act [42 U.S.C. 5121 et seq.]."

24) "The terms 'remedy' or 'remedial action' means those actions consistent with permanent remedy taken instead of or in addition to removal actions in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment. The term includes, but is not limited to, such actions at the location of the release as storage, confinement, perimeter protection using dikes, trenches, or ditches, clay cover, neutralization, cleanup of released hazardous substances and associated contaminated materials, recycling or reuse, diversion, destruction, segregation of reactive wastes, dredging or excavations, repair or replacement of leaking containers, collection of leachate and runoff, onsite treatment or incineration, provision of alternative water supplies, and any monitoring reasonably required to assure that such actions protect the public health and welfare and the environment. The term includes the costs of permanent relocation of residents and businesses and community facilities where the President determines that, alone or in combination with other measures, such relocation is more cost-effective than and environmentally preferable to the transportation, storage, treatment, destruction, or secure disposition offsite of hazardous substances, or may otherwise be necessary to protect the public health or welfare; the term includes offsite transport and offsite storage, treatment, destruction, or secure disposition of hazardous substances and associated contaminated materials."

(25) "The terms 'respond' or 'response' means remove, removal, remedy, and remedial action; all such terms (including the terms 'removal' and 'remedial action') include enforcement activities related thereto."

(33) "The term 'pollutant or contaminant' shall include, but not be limited to, any element, substance, compound, or mixture, including disease-causing agents, which after release into the environment and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will or may reasonably be anticipated to cause death, disease,

behavioral abnormalities, cancer, genetic mutation, physiological malfunctions (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring…"

§9604 (a)(1)"Whenever (A) any hazardous substance is released or there is a substantial threat of such a release into the environment, or (B) there is a release or substantial threat of release into the environment of any pollutant or contaminant which may present an imminent and substantial danger to the public health or welfare, the President is authorized to act, consistent with the national contingency plan, to remove or arrange for the removal of, and provide for remedial action relating to such hazardous substance, pollutant, or contaminant at any time (including its removal from any contaminated natural resource), or take any other response measure consistent with the national contingency plan which the President deems necessary to protect the public health or welfare or the environment."

(4)"…the President may respond to any release or threat of release if in the President's discretion, it constitutes a public health or environmental emergency and no other person with the authority and capability to respond to the emergency will do so in a timely manner."

(h) "Emergency procurement powers; exercise by President

Notwithstanding any other provision of law, subject to the provisions of section 9611 of this title, the President may authorize the use of such emergency procurement powers as he deems necessary to effect the purpose of this chapter. Upon determination that such procedures are necessary, the President shall promulgate regulations prescribing the circumstances under which such authority shall be used and the procedures governing the use of such authority."

§9605 (8)(A) "…criteria for determining priorities among releases or threatened releases throughout the United States for the purpose of taking remedial action and, to the extent practicable taking into account the potential urgency of such action, for the purpose of taking removal action. Criteria and priorities under this paragraph shall be based upon relative risk or danger to public health or welfare or the environment, in the judgment of the President, taking into account to the extent possible the population at risk, the hazard potential of the hazardous substances at such facilities, the potential for contamination of drinking water supplies, the potential for direct human contact, the potential for destruction of sensitive ecosystems, the damage to natural

resources which may affect the human food chain and which is associated with any release or threatened release, the contamination or potential contamination of the ambient air which is associated with the release or threatened release, State preparedness to assume State costs and responsibilities, and other appropriate factors…"

§9615(b) "The Administrator shall transfer to other agencies, from the Hazardous Substance Superfund out of sums appropriated, such amounts as the Administrator may determine necessary to carry out the purposes of the Act. These amounts shall be consistent with the President's Budget, within the total approved by the Congress, unless a revised amount is approved by OMB. Funds appropriated specifically for the Agency for Toxic Substances and Disease Registry (``ATSDR"), shall be directly transferred to ATSDR, consistent with fiscally responsible investment of trust fund money."

(i) "Funds from the Hazardous Substance Superfund may be used, at the discretion of the Administrator or the Coast Guard, to pay for removal actions for releases or threatened releases from facilities or vessels under the jurisdiction, custody or control of Executive departments and agencies but must be reimbursed to the Hazardous Substance Superfund by such Executive department or agency."

§9618, "High priority for drinking water supplies", may be applied should the release involve possible contamination of a drinking water source.

"For purposes of taking action under section 9604 or 9606 of this title and listing facilities on the National Priorities List, the President shall give a high priority to facilities where the release of hazardous substances or pollutants or contaminants has resulted in the closing of drinking water wells or has contaminated a principal drinking water supply."